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HIGH SPEED AERONAUTICS

HEARING

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

NINETY-NINTH CONGRESS

FIRST SESSION

JULY 24, 1985

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HIGH SPEED AERONAUTICS

WEDNESDAY, JULY 24, 1985

HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND TECHNOLOGY, SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS,

Washington, DC.

The subcommittee met, pursuant to notice, at 9:35 a.m., in room 2325, Rayburn House Office Building, Hon. George E. Brown, Jr. (chairman of the subcommittee) presiding.

Present: Representatives Brown, Glickman, Reid, Nelson, Lewis, Packard, and Lujan [ex officio].

STATEMENT OF HON. GEORGE E. BROWN, JR., A U.S. REPRESENTATIVE FROM THE STATE OF CALIFORNIA

Mr. BROWN. The subcommittee will come to order.

We are taking up an extremely important subject this morning with an outstanding list of witnesses. We are looking forward to hearing from all of them. I have a brief opening statement which we will proceed with at this time.

I am pleased to join with my colleague, Dan Glickman, in holding this hearing on what I feel is a very exciting frontier of aviation technology, exciting not only because of the potential for much faster air travel and substantially cheaper access to space, but also because of the fallout in a number of very important technological areas.

For example, I have long been interested in the benefits of hydrogen as a fuel and in the potential for new materials, both of which, if developed in the context of this program in aeronautics, will find much wider applications. It is also true that the development of hypersonic technology will depend heavily on supercomputers, a trend that will have widespread benefits.

I am particularly pleased that this country seems to be resuming its long quest to expand the aviation envelope. We backed away from our first run at high speed civil aeronautics almost 15 years ago, a decision that I believe was probably correct for a number of reasons at that time, not the least of which was economic.

At that time, the speed was supersonic, but technology has moved forward since then, and we may be in a position today to move beyond supersonic into the hypersonic area.

So, I am gratified to be participating in these hearings so that we can understand the needs and opportunities for this advance in aviation.

I would like to call on Mr. Lewis for any opening statement that he might have.

STATEMENT OF HON. TOM LEWIS, A U.S REPRESENTATIVE FROM THE STATE OF FLORIDA

Mr. LEWIS. Thank you, Mr. Chairman.

The shift in emphasis from subsonic aeronautics to high speed is a welcome change. We have neglected this important technology for too long. The competition is not waiting for us, and we simply cannot afford to drag our feet any longer.

Much has been said about the growing importance of the Pacific Basin and the need to develop a faster means of transportation to meet the market demands in this area. There also has been a growing awareness that we need to develop a more efficient means of space transportation and reduce the costs of putting payloads into orbit. An aerospace plane that can take off and land from conventional runways and reach orbital speeds promises to do that. A transatmospheric vehicle that can take off and land horizontally is an exciting concept.

Apparently, others agree. The British are already working on this concept. They call it the Hotal, short for horizontal takeoff and landing, and they hope to have it flying by 1997. They estimate that they will be able to put a satellite into orbit for one-half to one-fifth the cost of our shuttle launches, and they predict they will have 75 percent of the commercial launch market by the year 2000.

It is clear that if we don't want to play catch-up, we will have to move very fast. The competition is not waiting for us.

These are ambitious goals, high speed transportation for the Pacific rim market and a single stage to orbit aerospace plane. However, these are goals that I believe have the support of the American people. Accomplishing these goals represents a formidable challenge, but it is a challenge we must accept. We cannot afford not to.

It will be costly. Developing the technology for these missions will require a major commitment on the part of the administration, the Congress, and the American people. And the fiscal realities facing us today demand that we make every effort to make our research dollars accomplish more than ever before.

Much of the technology that will be needed for a transatmospheric vehicle should be applicable to the next generation high speed transport. Will it be enough to enable our aircraft industry to develop an economically viable supersonic or hypersonic transport, or will it be necessary to build and flight test technology demonstrators for both missions? Should these goals be pursued in parallel, or should we go forward now with the technology demonstrator for the transport mission and follow this later with a transatmospheric vehicle?

These are the questions that I hope will be answered this morning. We should not be attempting to design the next generation high speed transport at this hearing, but it is important that we have a clear understanding of the challenges that lie ahead of us and how we hope to meet them.

Thank you, Mr. Chairman.

Mr. BROWN. Thank you.

The chairman of this subcommittee for the first 6 months of this year was Dan Glickman, and he is the one who actually arranged

these hearings with, of course, the able assistance of the staff. He will be back shortly, but in the event he doesn't come back in time, he has an opening statement which I would like to put in the record, and he can amplify on it when he comes back.

[The prepared opening statement of Mr. Glickman follows:]

OPENING STATEMENT

HONORABLE DAN GLICKMAN
SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

JULY 24, 1985

HIGH SPEED AERONAUTICS

IN 1963, JOE WALKER FLEW THE EXPERIMENTAL, ROCKET-POWERED X-15 TO A RECORD ALTITUDE OF 354,000 FEET. IN 1967, COL. WILLIAM KNIGHT SET THE SPEED RECORD AT 4500 MILES PER HOUR.

THESE RECORDS STILL STAND TODAY! NOTHING, IN THE 18 YEARS SINCE, HAS VENTURED BEYOND THESE LIMITS. THE ONLY EXCEPTIONS HAVE BEEN MANNED SPACECRAFT, WHICH HAVE MERELY PASSED THROUGH THE UPPER ATMOSPHERE ON THEIR WAY TO AND FROM ORBIT.

WHY HAS THERE BEEN NO FLIGHT RESEARCH TO EXPLORE THE VAST SPEED AND ALTITUDE ENVELOPE LYING BETWEEN THE UPPER REACH OF THE X-15 AND SPACE? IS IT BECAUSE THERE IS NO FORESEEABLE UTILITY? I THINK NOT. THE ENTIRE HISTORY OF AVIATION IS ONE OF CONSTANT STRIVING TO GO HIGHER AND FASTER. AND WE'VE ALWAYS GAINED PROFOUND BENEFITS FROM DOING SO. I DON'T THINK WE'VE REACHED AN UPPER LIMIT OR SOME TECHNOLOGICAL BARRIER THROUGH WHICH WE CAN'T PASS. RATHER, I BELIEVE WE MUST CONTINUE TO PUSH INTO THE UNKNOWN.

IS IT BECAUSE WE'VE LOST OUR NERVE, OUR WILLINGNESS TO TAKE RISKS? I DON'T BELIEVE THAT EITHER. BUT I DO THINK WE HAVE WASTED VALUABLE TIME. WE CAN'T PRESERVE OUR LONG-HELD PREEMINENCE IN AVIATION BY MAKING INCREMENTAL IMPROVEMENTS. OTHER COUNTRIES ARE RAPIDLY ACQUIRING THE ABILITY TO DO THAT. TO REMAIN NUMBER ONE, WE HAVE TO SEEK THE REVOLUTIONARY CHANGE, THE BREAKTHROUGH. WE MUST LEAPFROG THE OTHERS.

AND THAT IS WHAT THIS HEARING IS ABOUT TODAY. WE WANT TO KNOW WHAT KINDS OF MILITARY AND COMMERCIAL REQUIREMENTS WILL IMPEL US TO GO HIGHER AND FASTER, WHAT TECHNOLOGIES WILL BE NEEDED TO MOVE BEYOND THE X-15 ENVELOPE, AND WHAT KINDS OF AIRCRAFT WILL BE POSSIBLE IN THE NEXT CENTURY.

TO ASSIST IN THIS EXAMINATION, WE HAVE INVITED A MOST DISTINGUISHED AND KNOWLEDGEABLE GROUP OF WITNESSES.

WE ARE PARTICULARLY FORTUNATE TO HAVE, AS OUR LEAD WITNESS, THE PRESIDENT'S SCIENCE ADVISORY, DR. JAY KEYWORTH.

DR. KEYWORTH, AS MOST OF YOU KNOW, HAS TAKEN A STRONG PERSONAL INTEREST IN THIS SUBJECT, HAVING PRESIDED OVER THE ENUNCIATION OF THREE COMPREHENSIVE NATIONAL AERONAUTICAL R&D GOALS. TWO OF THESE RELATE TO THE SUBJECT TODAY -- HIGH SPEED AERONAUTICS. SO, WE'RE ESPECIALLY PLEASED THAT DR. KEYWORTH COULD BE HERE.

Mr. BROWN. Now I would like to recognize Mr. Nelson for any statement that he might have.

STATEMENT OF HON. BILL NELSON, A U.S REPRESENTATIVE FROM THE STATE OF FLORIDA

Mr. NELSON. Mr. Chairman, this is an exciting subject. The potentiality here of the Orient Express[1] and the technologies that may be discussed may have some application with regard to what Mr. Lewis has just said about the British about inserting on into orbit. From our perspective on the Space Subcommittee, we are exceptionally excited about these possibilities.

However, more directly to the point of our hearing today, Mr. Chairman, at each occasion that I have had the opportunity to speak on behalf of research and development, additional money for research and development for aviation, I have done so, because simply the future economic vitality of this country depends on our development of research and development in the high technology area.

One of the areas that the United States has been so preeminent has been in aviation, and now we are being seriously challenged in aviation. The breakthrough of this kind of technology that is the subject of this hearing today would surge us to the fore again. I just think that for the sake of this country, we have to proceed with all due diligence and resolve.

I would like to add a formal statement for the record.

Mr. BROWN. Without objection, so ordered.

[The prepared opening statement of Mr. Nelson follows:]

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[1] See appendix.

Statement by Hon. Bill Nelson

Subcommittee on Transportation, Aviation, and Materials

Hearing on Next Century High Speed Aircraft

July 24, 1985

Recently, the leadership of the Space Science and Applications Subcommittee was briefed concerning the eventual space applications of the emerging technologies, that DARPA will be discussing here today.

I must say that we were intrigued with the operating potential and possible launch economies that these technologies may make available to the space community and therefore are supportive of research efforts to pursue the development of these technologies.

I know that the thrust of today's hearing is the applicability of these technologies to hypersonic transport aircraft. Accordingly I will reserve my questions regarding application of these technolgoies to the space arena for a later time at which the Space Science and Applications Subcommittee will hold a hearing devoted specifically to that topic.

Mr. BROWN. Thank you, Mr. Nelson.

Mr. Packard, do you have any opening statement?

STATEMENT OF HON. SHERWOOD PACKARD, A U.S. REPRESENTATIVE FROM THE STATE OF CALIFORNIA

Mr. PACKARD. I didn't intend to make any opening statement, but, simply, I think the American people generally are not aware of the correlation between many programs that are ongoing that I think will set the direction for the future of this country. Aviation has been mentioned. Of course, our space program is tied in with what we will be discussing this morning. I think our space defense initiative will have some significant spinoffs and benefits coming from what we will be discussing today.

So, I think many of the major future programs of America have a direct correlation with the item that we will be discussing today. I thank the chairman for setting up and organizing such a hearing.

Thank you.

Mr. BROWN. Without objection, the Chair will grant approval for photographers here this morning for both still and moving pictures.

We welcome you, Dr. Keyworth. We consider this, as you have observed from the statements, extremely important. We know of your own interest in it. I have a personal interest in getting you on the record here, because this is an area in which Federal leadership is so important, and I think you have come to recognize that. We hope you will come to recognize that in some other areas as well.

You may proceed with your statement.

STATEMENT OF DR. GEORGE A. KEYWORTH II, DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY, EXECUTIVE OFFICE OF THE PRESIDENT

Dr. KEYWORTH. Mr. Chairman, if I can, I would appreciate the opportunity to simply summarize my prepared statement.

Mr. BROWN. Without objection.

Dr. KEYWORTH. Two years ago, when I last addressed this subcommittee, I described the position this country faces in aeronautics. On the one hand, truly revolutionary advances in aeronautics technology portend new civilian and military aircraft of vastly superior performance to anything that is flying today. On the other hand, the rising technical capabilities of our international competitors and adversaries seriously challenge our historic leadership. Our challenge is to continue to find ways to direct our research and technology development toward those areas that can maintain our competitive edge and leadership.

Mr. Chairman, in aeronautics as well as in countless other areas of technology, we confront a revolution that continually challenges our vision. We have two choices. We can try to protect the present by continuing our emphasis on such issues as the competition to our own space and aviation leadership from Ariane and Airbus or the expanding Soviet efforts in aeronautics and space, or we can seek to capture the future that is held out to us by our own vigor

and progress in such diverse fields of research as materials, propulsion, avionics, and design.

To me, the question is more fundamental than aeronautics alone. It is a question of whether we have the foresight and the courage to retain our post-war position of technological and concomitantly economic leadership.

With those few comments, Mr. Chairman, in recognition that I think we are all in apparent agreement that nothing is more exciting today than the opportunities in aeronautics technology, I would like to attempt to answer your questions, if I may.

[The prepared statement of Dr. Keyworth follows:]

PROPOSED TESTIMONY OF DR. G. A. KEYWORTH, II,
SCIENCE ADVISOR TO THE PRESIDENT, AND
DIRECTOR, OFFICE OF SCIENCE AND TECHNOLOGY POLICY
EXECUTIVE OFFICE OF THE PRESIDENT

TO THE UNITED STATES HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS
JULY 24, 1985

MR. CHAIRMAN AND MEMBERS OF THE SUBCOMMITTEE:

I'M PLEASED TO JOIN YOU FOR THESE HEARINGS ON THE SUBJECT OF AERONAUTICS. THIS MORNING I WANT TO DESCRIBE IN BROAD TERMS OUR GOALS FOR AERONAUTICAL RESEARCH AND TECHNOLOGY, OUR VIEW OF THE NEED FOR THE COUNTRY TO MAINTAIN ITS PREEMINENCE IN THIS FIELD, AND THE MEANS BY WHICH TO DO THAT. LATER IN THIS SESSION OTHER SPEAKERS WILL DESCRIBE SPECIFIC RESEARCH PROGRAMS BEING CONDUCTED TO SUPPORT THIS ENDEAVOR.

TWO YEARS AGO, WHEN I LAST ADDRESSED THIS SUBCOMMITTEE, I DESCRIBED THE POSITION THIS COUNTRY FACES IN AERONAUTICS. ON THE ONE HAND TRULY REVOLUTIONARY ADVANCES IN AERONAUTICS TECHNOLOGY PORTEND NEW CIVILIAN AND MILITARY AIRCRAFT OF VASTLY SUPERIOR PERFORMANCE TO ANYTHING FLYING TODAY. BUT ON THE OTHER HAND, THE RISING TECHNICAL CAPABILITIES OF OUR INTERNATIONAL COMPETITORS AND ADVERSARIES SERIOUSLY CHALLENGE OUR HISTORIC LEADERSHIP. OUR CHALLENGE IS TO CONTINUE TO FIND WAYS TO DIRECT OUR RESEARCH AND TECHNOLOGY DEVELOPMENT TOWARDS THOSE AREAS

THAT CAN MAINTAIN OUR COMPETITIVE EDGE.

MR. CHAIRMAN, THE ADMINISTRATION HAS BEEN PAYING PARTICULAR ATTENTION TO AERONAUTICAL R&D POLICY, AND I'D LIKE TO SUMMARIZE THOSE ACTIVITIES FOR YOU. IN 1982 WE ISSUED A NATIONAL POLICY FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN WHICH WE RECOGNIZED THE IMPORTANCE OF AERONAUTICS TO THE COUNTRY'S STRATEGIC AND ECONOMIC INTERESTS AND REAFFIRMED THE GOVERNMENT'S COMMITMENT TO JOIN INDUSTRY IN ENSURING THE WORLD'S STRONGEST TECHNOLOGY BASE FOR AERONAUTICS.

FOLLOWING UP ON THIS POLICY, I ESTABLISHED AN AERONAUTICAL POLICY REVIEW COMMITTEE MADE UP OF DISTINGUISHED REPRESENTATIVES FROM INDUSTRY, GOVERNMENT, AND UNIVERSITIES TO ASSIST US IN IMPLEMENTING THE POLICY AND IN IMPROVING THE COORDINATION OF AERONAUTICAL ACTIVITIES. THEIR INITIAL TASK WAS TO UNDERTAKE A COMPREHENSIVE SURVEY OF THE RESEARCH OPPORTUNITIES IN AERONAUTICS. THEY CONCLUDED THAT TREMENDOUS POTENTIAL EXISTS FOR BOLD ADVANCES IN AERONAUTICAL TECHNOLOGY AND THAT OUR CONTINUED LEADERSHIP WOULD REQUIRE A VIGOROUS RESEARCH PROGRAM TO CAPTURE THAT POTENTIAL. WE DISCUSSED THOSE FINDINGS WITH THIS SUBCOMMITTEE IN DECEMBER OF 1983, AND I BELIEVE WE GENERALLY AGREED THAT GOVERNMENT HAS AN IRREPLACEABLE ROLE IN PURSUING MANY OF THOSE HIGH-RISK/HIGH-PAYOFF TECHNOLOGIES THAT ARE NECESSARY TO

ENSURE U.S. AERONAUTICS LEADERSHIP.

IN ORDER TO PROVIDE A FOCUS FOR OUR RESEARCH EFFORTS I AGAIN CALLED ON THE AERONAUTICAL POLICY REVIEW COMMITTEE. THREE MONTHS AGO I RELEASED A REPORT BY THE COMMITTEE PROPOSING A SEQUENCE OF NATIONAL GOALS FOR AERONAUTICAL RESEARCH AND DEVELOPMENT. WE BELIEVE THAT THIS REPORT WILL HELP FOCUS PUBLIC AND PRIVATE SECTOR ATTENTION ON THE R&D NEEDED TO SUSTAIN AMERICA'S PREEMINENCE IN AERONAUTICS INTO THE NEXT CENTURY. THE REPORT DISCUSSED GOALS IN THREE OPERATING REGIMES: SUBSONIC, SUPERSONIC, AND HYPERSONIC AND TRANS-ATMOSPHERIC.

THE FIRST OF THE GOALS FOCUSES ON ADVANCED TECHNOLOGIES TO BE USED IN A NEW GENERATION OF SUBSONIC AIRCRAFT. A LARGE AMOUNT OF RESEARCH HAS BEEN DONE OVER THE PAST SEVERAL YEARS IN THE AREAS OF COMPOSITE STRUCTURES, LAMINAR FLOW CONTROL, DIGITAL FLIGHT CONTROLS, AND HIGH-BYPASS, FUEL-EFFICIENT ENGINES. AS THESE TECHNOLOGIES MATURE TOWARD THE END OF THE DECADE, WE CAN EXPECT INDUSTRY TO DESIGN AND MARKET A NEW GENERATION OF HIGH-EFFICIENCY AIRCRAFT INCLUDING TRANSPORTS, COMMUTERS, AND ROTORCRAFT.

MR. CHAIRMAN, THE IMPORTANCE OF ADVANCES IN THIS SUBSONIC REGIME TO U.S. AVIATION LEADERSHIP IS IMMENSE, AND I WANTED TO BE SURE TO MENTION IT. HOWEVER, FOR THE PURPOSES OF THESE HEARINGS, I WANT TO CONCENTRATE ON THE

OTHER TWO GOALS FROM THE REPORT--THOSE RELATING TO SUPERSONIC AND TRANSATMOSPHERIC FLIGHT.

ONE OBVIOUS GROWING NEED OF OUR CHANGING WORLD IS TO HAVE READY AND CONVENIENT ACCESS TO THE PACIFIC. HAVING JUST LAST WEEK COMPLETED A TRIP TO CHINA, I SPEAK WITH AUTHORITY--AND SOME RESIDUAL WEARINESS--ON AN EXPERIENCE I'M SURE A FEW OF YOU HAVE SHARED--THE 22-HOUR FLIGHT HOME. CONSIDERING THE GROWING STRATEGIC AND ECONOMIC INTERACTIONS BETWEEN THE UNITED STATES AND CHINA, JAPAN, AND OTHER COUNTRIES AROUND THE PACIFIC RIM, WE SEE A GROWING DEMAND FOR MEANS TO BRING OUR SHORES CLOSER TOGETHER. SATELLITE COMMUNICATIONS AND FIBER-OPTIC OCEAN CABLES ARE TREMENDOUS ADVANCES IN OUR ABILITY TO TRANSMIT INFORMATION BACK AND FORTH, BUT ADVANCES IN TELECOMMUNICATIONS HAVE INCREASED DEMAND FOR TRANSPORTATION, NOT REPLACED IT.

THIS EMERGING NEED FOR MORE READY ACCESS TO ASIA IS ONE OF THE DRIVING FORCES FOR THE SECOND OF THE AERONAUTICAL R&D GOALS--ADVANCED TECHNOLOGIES FOR LONG-DISTANCE, SUSTAINED SUPERSONIC CRUISE. IT'S TRUE THAT CONCEPTS TO MEET THIS REQUIREMENT HAVE BEEN AROUND FOR DECADES, BUT THE CHALLENGE TO OUR TECHNOLOGY IS THE REQUIREMENT OF COMMERCIAL SUCCESS--NOT JUST SUPERSONIC TRANSPORT, BUT AFFORDABLE SUPERSONIC TRANSPORTATION.

WHAT WE SEE NOW, HOWEVER, IS THE GENESIS OF NEW TECHNOLOGIES, ESPECIALLY IN THE AREAS OF MATERIALS AND PROPULSION, WHICH MAY WELL MAKE SUCH VEHICLES ECONOMICALLY VIABLE BEFORE THE END OF THE CENTURY. THIS COUNTRY HAS THREE DECADES OF ENGINEERING AND FLIGHT EXPERIENCE WITH VEHICLES THAT TRAVEL AT SPEEDS GREATER THAN THAT OF SOUND. IT'S TIME WE BUILD ON THAT EXPERIENCE AND USE THE TALENT THAT STILL EXISTS TO FURTHER DEVELOP THESE TECHNOLOGIES IN SERVICE TO OUR NATIONAL NEEDS.

THE THIRD AERONAUTICS GOAL, AND PERHAPS THE MOST IMPORTANT, ADDRESSES THE CONVERGENCE OF ATMOSPHERIC FLIGHT AND SPACE FLIGHT. LET ME SUGGEST AN ANALOGY. OUR SUCCESSFUL INTERNATIONAL COMMERCE DEPENDS ON A ROBUST AIRLINE AND AIRPORT SYSTEM INCORPORATING REGULAR AND RELIABLE AIRCRAFT SERVICE. IN A SIMILAR FASHION, OUR NATIONAL SECURITY INTERESTS ARE SERVED BY AN INTERNATIONAL FORCE PROJECTION CAPABILITY THAT'S BUILT ON OUR SUPERIOR AIRPOWER. AS SPACE EVOLVES AS A REGION OF INCREASING IMPORTANCE TO OUR NATIONAL COMMERCIAL AND STRATEGIC INTERESTS, THIS SAME REGULAR AND RELIABLE ACCESS TO IT AS TO THE LOWER ATMOSPHERE WILL BE REQUIRED. FOR THIS REASON, THAT THIRD GOAL DIRECTS OUR RESEARCH AND DEVELOPMENT EFFORTS TO CONCENTRATE ON THOSE TECHNOLOGIES THAT WILL PROVIDE TRANSATMOSPHERIC FLIGHT CAPABILITY.

I'M PERSONALLY MOST EXCITED ABOUT THIS AREA OF

OPPORTUNITY, BECAUSE IT WILL FINALLY ENABLE US TO BRIDGE THE GULF BETWEEN OPERATIONS IN SPACE AND THOSE IN THE ATMOSPHERE. TRANSATMOSPHERIC VEHICLES WILL BE ABLE TO OPERATE EFFICIENTLY IN BOTH. AND WHAT WILL EMERGE IS A HITHERTO UNHEARD-OF ABILITY TO TRAVEL RAPIDLY, ON SHORT NOTICE AND WITH SHORT TURNAROUND TIME, TO ANY OF OUR SPACE PLATFORMS OR TO ANY POINT ON THE GLOBE.

OF COURSE, THESE AND OTHER AMBITIOUS VISIONS CAN ONLY COME ABOUT IF WE AS A NATION EMBRACE THE RIGOROUS AND PERHAPS RISKY TASK OF DEVELOPING THE APPROPRIATE TECHNOLOGIES. BUT I BELIEVE THAT THIS COUNTRY IS IN AN ENVIABLE POSITION TO DO JUST THAT. WE HAVE BOTH THE TALENT AND THE STRONG TECHNICAL BASE TO ACHIEVE ALL THREE NATIONAL GOALS.

MR. CHAIRMAN, I'D LIKE TO TAKE A FEW MINUTES TO DESCRIBE HOW WE'RE FOLLOWING UP ON THE ISSUANCE OF THOSE NATIONAL GOALS EARLIER THIS YEAR.

FIRST, IMMEDIATELY AFTER THE COMMITTEE PRESENTED THEM, I ASKED THAT THEY CREATE A TECHNOLOGY PLAN TO IMPLEMENT THE GOALS, OR "ROADMAPS" AS WE CALL THEM. NASA DEVISED A PRELIMINARY VERSION OF THESE ROADMAPS, AND THE COMMITTEE IS SPECIFYING THE INDIVIDUAL STEPS NEEDED TO BRING THE DIVERSE RANGE OF TECHNOLOGIES ENCOMPASSED IN THE THREE GOALS TO MATURITY AND READINESS.

SECOND, AS YOU WILL HEAR SHORTLY FROM NASA AND DARPA, THE FEDERAL R&D AGENCIES THAT DEVELOP ADVANCED TECHNOLOGIES IN AERONAUTICS ARE ALTERING THEIR CURRENT RESEARCH PROGRAMS AND INITIATING OTHERS MORE CLOSELY IN LINE WITH THESE GOALS.

THIRD, WE'VE ALSO CONSIDERED HOW THESE NEXT-GENERATION AIRCRAFT WILL FUNCTION IN THE FUTURE AIR TRAFFIC CONTROL SYSTEM. ONE OF THE MANDATES OF THE ORIGINAL 1982 POLICY WAS THAT ALL TECHNICAL ADVANCES IN AIRCRAFT AND THEIR SYSTEMS MUST COINCIDE WITH A COORDINATED IMPROVEMENT IN THE AIRSPACE SYSTEM IN WHICH THESE VEHICLES WOULD OPERATE. TO THAT END, MY OFFICE IS WORKING WITH THE DEPARTMENT OF TRANSPORTATION AND THE FEDERAL AVIATION ADMINISTRATION TO ENSURE THAT TECHNOLOGIES FOR AIRCRAFT AND AIRSPACE SYSTEM KEEP PACE WITH ONE ANOTHER.

FOURTH, WE'RE GOING TO THE UNIVERSITY RESEARCH COMMUNITY TO DISCUSS THE IMPLICATIONS FOR BASIC RESEARCH. THE MORE CLOSELY THE ACADEMIC COMMUNITY IS INVOLVED IN THESE NEW EMPHASES IN AERONAUTICS, THE GREATER THEIR CONTRIBUTIONS TO DEVELOPING THE TECHNOLOGIES. IN PARTICULAR, WE WANT THEM TO BE ABLE TO PREPARE THEIR STUDENTS TO ADDRESS THE TECHNICAL CHALLENGES THEY'RE GOING TO FACE IN INDUSTRY.

AND FIFTH, WE'RE MAKING SURE THAT INDUSTRY IS AWARE OF

THE SCOPE OF THE GOALS AND REALIZES THAT THEY BEAR MUCH OF THE BURDEN OF ACHIEVING THEM. THE GOVERNMENT WILL CONTINUE TO PROVIDE BROAD SUPPORT FOR FUNDAMENTAL STUDIES IN AERONAUTICS, BUT IT'S THE PRIVATE SECTOR THAT'S GOING TO HAVE TO BRING TO THIS PARTNERSHIP THE RESOURCES TO MOVE THESE TECHNOLOGICAL ADVANCES INTO APPLICATION.

MR. CHAIRMAN, AS I'VE DISCUSSED WITH THE SUBCOMMITTEE BEFORE, AERONAUTICS IS IN A RENAISSANCE. WE SHOULD BE ABLE TO ACHIEVE VAST CHANGES IN THE WAY WE FLY FROM HERE TO ANOTHER CITY, TO ANOTHER CONTINENT, OR INTO ORBIT BY THE TURN OF THE CENTURY. WHAT WE HOPE TO ACHIEVE BY ISSUING THESE NATIONAL GOALS FOR AERONAUTICS RESEARCH IS A FOCUS FOR A NATIONAL EFFORT TO REALIZE THESE OPPORTUNITIES. IN A PROGRAMMATIC SENSE, IT WILL REQUIRE THE EXPEDITIOUS USE OF OUR RESOURCES--TALENT AND DOLLARS--TO BUILD UPON THE EXISTING TECHNOLOGY BASE AND TO DEVELOP AND WISELY APPLY THE NEW TECHNOLOGY TO BUILDING VEHICLES OF THESE CAPABILITIES. IN A MORE GLOBAL SENSE, IT REQUIRES THE UNITED STATES TO STEP UP TO MEET THE CHALLENGE FROM OUR COMPETITORS AND AGAIN DEMONSTRATE AMERICAN LEADERSHIP IN AERONAUTICS IN THE AIR AND OUT INTO SPACE.

MR. CHAIRMAN, IN AERONAUTICS AS WELL AS IN COUNTLESS OTHER AREAS OF TECHNOLOGY, WE CONFRONT A REVOLUTION THAT CHALLENGES OUR VISION. WE HAVE TWO CHOICES: WE CAN TRY TO PROTECT THE <u>PRESENT</u>, BY CONTINUING OUR EMPHASIS ON SUCH

ISSUES AS THE COMPETITION TO OUR OWN SPACE AND AVIATION LEADERSHIP FROM ARIANE AND AIRBUS OR THE EXPANDING SOVIET EFFORTS IN AERONAUTICS AND SPACE--OR WE CAN SEEK TO CAPTURE THE FUTURE HELD OUT TO US BY OUR OWN VIGOR AND PROGRESS IN SUCH FIELDS OF RESEARCH AS MATERIALS, PROPULSION, AVIONICS, AND DESIGN. THE QUESTION IS MORE FUNDAMENTAL THAN AERONAUTICS ALONE; IT'S A QUESTION OF WHETHER WE HAVE THE FORESIGHT AND COURAGE TO RETAIN OUR POST-WAR POSITION OF TECHNOLOGICAL, AND CONCOMITTANTLY, ECONOMIC LEADERSHIP.

MR. CHAIRMAN, THIS CONCLUDES MY FORMAL TESTIMONY. I WOULD BE PLEASED TO ANSWER ANY QUESTIONS FROM THE COMMITTEE.

Mr. BROWN. You did very well, Dr. Keyworth.

Dr. Keyworth, am I correct in my understanding that there is a report in preparation which will deal with the specific goals and resource requirements in this area which is expected to be ready sometime next year?

Dr. KEYWORTH. Yes, most certainly. We, as you well know, Mr. Chairman, 3 years ago set up a panel to attempt to define realistic goals for our own development in aeronautics. They have done that. Now, they are attempting to refine and specify, if you wish, the steps to achieving those goals.

I might just add, incidentally, that this group, composed of people from government, industry, and academia, has been a powerful means for bringing together focus from those three dimensions of our society toward recognition of what the potential is here. That may very well have been the single most important product of their long activity.

Mr. BROWN. The single most important product is what?

Dr. KEYWORTH. Is the fact that we have now brought a united focus to the fact that there is an enormous potential—and I really mean to emphasize this, Mr. Chairman—I think bigger than most of us, certainly bigger than I myself expected to see before us as soon as 1985.

Mr. BROWN. I thought you might be emphasizing the model of procedure here in which we brought together the three sectors in an effective way to set national goals and to mobilize or to develop more momentum behind those national goals.

Dr. KEYWORTH. Both. Most certainly. In fact, if I may say very generally, I think one of the things that we must restore if we are to become a truly competitive nation again is a too long missing sense of team work which is exemplified in this activity.

Mr. BROWN. We appreciate that.

Mr. Nelson, do you have any questions at this point?

Mr. NELSON. Mr. Chairman, I was out of the room during your particular statement. I take it that your statement is in support of proceeding with this technology.

In looking at this, and yet as I have seen it, people can get quite excited about this Orient Express, and yet everybody sort of shuffles around. What do we have to do to get the thrust going, Dr. Keyworth?

Dr. KEYWORTH. Mr. Nelson, I don't interpret what you refer to as the shuffling around as quite that. I think we have seen, as recently as the last 6 months, technologies rapidly pulling together to give us a clear definition of just what that opportunity is. Is it a supersonic vehicle? Is it a hypersonic vehicle? Is it a transatmospheric vehicle?

The dimensions and the clarity of the opportunity are only now appearing before us. I think that is why these hearings are important. I think it is why, in the course of this fall's budget development, it is going to be mandatory that we focus our efforts on this opportunity. It was not clearly there 2 years ago.

I would also offer this. I think we must all be very cautious not to overdefine exactly what these opportunities are here. I hear reference to Orient Express. I hear reference made to a transatmospheric vehicle, mach 3, mach 5, mach x. That is not the point.

The point is that travel from here to the Pacific Basin can be made routine and simple. Having just come back myself a few days ago from China and experiencing again and again that 22-hour flight, I am most certainly sensitive to that.

I think we can look forward to access to space, not, if I may be so optimistic, at a factor of 5 times cheaper than what we are experiencing today with the shuttle, but I would be so bold as to look forward to a factor of 100. That is the kind of breakthrough that we are talking about. That is what is at our fingertips and waiting for us to grasp.

I would also be so bold as to say that I think it is possible to substantially beat the goals that have been established by the very innovative members of the British space community. It is not necessarily 1997. This technology is here. It is not waiting to be developed. It is simply waiting to be used and put together and assembled in an innovative fashion to retain our leadership in this area.

We don't have to do new fundamental research to develop the materials to fly at hypervelocity speeds. We believe the technology is here.

Mr. NELSON. That is an exciting statement, and you are stimulating my adrenalin right now. If that is the case, and we have that, and we recognize how important it is from an international competitive financial standpoint that we keep pressing the development of our technology to stay in the league, recognizing what is happening with labor rates in Third World nations and so forth in our international competitiveness in the international arena, then, with all that as a background, what do we do, Dr. Keyworth? You are the science adviser. What do we do to move out right now?

Dr. KEYWORTH. Specifically, I think we are going to have to work together in the next few months with those various elements of our Government that perform and support research and development in aeronautics to try to develop the most streamlines and well coordinated program with industry to focus sharply and clearly on a well defined goal. By well defined goal, I mean, I think an agreement is not far away, recognizing that there is a year well defined. I won't specify whether it is 1990 or 1993 or whatever, but it is most certainly in this century, well within this century, where we are going to introduce the next generation of civil aircraft that will keep the position that we have come to, unfortunately, with excessive complacency.

We have to pump energy into this objective. If I may go further, I think the most important thing is not exactly how the budget is structured. The most important thing is that it is going to be essential for this country to have some clear-cut goals for technology development that spell out our commitment to our young people and to the world that we are going to accept preeminence and only preeminence.

President Nixon said on television recently, much to the amazement of many people, that he felt that the single greatest contribution that he had made as President of the United States was his initiation of the war on cancer. Considering that President Nixon's war on cancer stimulated what we now call modern biology and virtually created biotechnology, I think his statement was an extremely visionary recognition.

By the same token, today I think the challenge is before us all to identify a small number of clear national goals, not models after Apollo, but clear models of what we can do and our commitment to being competitive on the basis of our technological excellence. I must say, I have searched, as many of you have, for years for the ideal opportunities. I tell you candidly I do not know of a single one better than this.

We presented to our White House Science Council recently a briefing of what to me is one of the most exciting programs I have been exposed to in this area. I have not seen them as enthusiastic toward any single opportunity as this that we are discussing in these hearings.

Mr. NELSON. Preparatory to my next question, I might point out that Mr. Scott Crossfield, a member of the staff of this subcommittee, was experimenting with this kind of technology years ago when he was a test pilot at Edwards Air Force Base. He, by the way, is the gentleman who was the first to break mach 2, so a lot of the basic technology has been around.

My question to you is, with the enthusiasm and I commend your enthusiasm and I encourage your enthusiasm, and we can all get together and really have an enthusiastic party, but my question to you is, when can we in the Congress expect to see the articulation of those national goals coming from the White House.

Dr. KEYWORTH. I was not elected to office. I cannot speak for what we as a government or an administration are going to do as a whole.

Mr. NELSON. You are the science advisor.

Dr. KEYWORTH. What I would say is this, I most certainly feel that we have an exceptional opportunity here. I am not sure that we have had a better opportunity in many decades to take a bold step forward to capture a market which is practical, an economic advantage for the United States, but perhaps more importantly to truly capture in an enduring way the imagination of our young people.

No question it is a statement to the world. We can do it. The opportunity is here. I believe it is an opportunity we should do our very best to seize in the course of the next year.

I don't mean to be redundant, Congressman, but if I could just make one clear statement, we are not talking about tomorrow's technologies. If we simply take design capabilities, avionics, materials, and, most important, the breakthroughs that have occurred in ramjet or scramjet technologies, put them together, we will take a leap of what would normally be treated as a two or three generation leap in aircraft technology. That is the opportunity before us. It is here.

Mr. NELSON. Amen. I agree. One further question, Mr. Chairman.

Might we see, then,—now let's get specific—might we see in the Administration's request to Congress for the budget an increase in the R&D budget for aviation under NASA?

Dr. KEYWORTH. It is premature to ask me that question. I do not mean to simply obfuscate. What I hope we will certainly see is a clear focus in NASA's and DARPA's budgets that makes this objec-

tive stand out clearly as a role that the Federal Government will play in concert with the aerospace industries.

Mr. NELSON. Instead of waiting until the Fiscal Year 1987 cycle, could we see that in a request for reprogramming and/or a supplemental request for fiscal year 1986?

Dr. KEYWORTH. There certainly are very important programs essential to meeting this endeavor that most certainly await reprogramming right now. That is under review, and I most certainly thoroughly support our beginning right now. Every minute counts. It is a test of our willingness to be competitive, to move, to recognize an opportunity and respond intelligently.

Mr. NELSON. Dr. Keyworth, your enthusiasm is appreciated.

Mr. BROWN. Thank you, Mr. Nelson.

The distinguished ranking minority member of the full committee has graced us with his presence, and I would like to ask him if he has an opening statement or any comments to make.

Mr. LUJAN. Thank you, Mr. Chairman. No, I don't. I just want to welcome Dr. Keyworth. I was very interested in the answers to Mr. Nelson's questions and very impressed with your enthusiasm. Thank you very much.

Dr. KEYWORTH. Thank you.

Mr. BROWN. Mr. Lewis.

Mr. LEWIS. Thank you, Mr. Chairman.

Dr. Keyworth, I did, while you were answering questions, really speed through your presentation, and it is a shame that you just didn't read it all because it is very exciting and does have an enthusiastic approach to the problems that we are discussing here this morning.

In your goals 2 and 3, is there a specific mach number that you are referring to, or are you basically speaking of different missions?

Dr. KEYWORTH. When we began our study in 1982 to focus on identifying goals, you may well remember that we focused upon three sequential goals, the high efficiency aircraft, the supersonic transport, and the less well defined hypersonic transatmospheric vehicle. I would be so bold as to say this: I think the second is an anachronism because I think it will be by-passed because suddenly we will find ourselves able to meet the third objective.

So, very specifically, what I think has been the major technological breakthrough is the ability to use scramjet technologies at extremely high altitude so that we can achieve very high mach numbers in excess of 10 to produce very high velocity flight. This is now, we believe, technologically feasible. It was not as recently as 2 or 3 years ago.

So, I think that the opportunity that is emerging among the aeronautics and aerospace experts is the realization that we can achieve very high mach numbers, very easy access into space where rocket propulsion carrying the onboard oxygen is only a minor requirement, with the possibility of coasting into orbit and simply using rocket capabilities for return and maneuvering. This is a true double jump in technology. We have simply skipped over what would be, if you wish, the commercially feasible supersonic transport.

This is the basis for my enthusiasm, incidentally. We have the opportunity to talk about very high mach numbers at potentially highly competitive economic conditions. We cannot tell until we get further along the developmental scale, for example, the question we all want to ask is how much money it is going to cost to fly to Tokyo in an hour. We can't answer that question, but I think we can talk seriously about that within a factor of 2 with enough knowledge to know that we are talking about prices that could be economically competitive with tickets today.

Mr. LEWIS. I see. You mentioned that you think a lot of the technology that we are talking about is here today. I had the opportunity to work back in the early 1960's on the SR-71 which was known as a different aircraft at that time, and a lot of those technologies could be applied, I believe, in today's atmosphere, building toward what you are pointing toward or looking at with your presentation and into the hypersonic regions. We already can fly faster than mach 3. We have that technology. We haven't been building on it for the past several years.

Do you feel that we could step up by using some of this technology and move right into a faster mode of development?

Dr. KEYWORTH. If there is one message I really would like to emphasize in my comments today it is one word, revolution. This is not an extension, a simple extension of where we were 5, 10, or 15 years ago. We are in the midst of a technological revolution that is unprecedented in history. We are seeing it in more areas than aeronautics.

The challenge before us is whether we can react and absorb the opportunities rapidly enough to capture them. You know, it is often said that half the knowledge we have of nature today has been gained in the last 25 years. That is a rapid rate of progress. It is nothing compared to the last 5 years and the next 5 years.

I say this, Mr. Lewis, in simply cautioning that this is not the ramjet technology of the 1960's extrapolated forward. This is not the 30 years of experience we have had in supersonic transport. We are talking about new materials, new design, new propulsion, new avionics that simply let us, if you wish, invent the next generation aircraft.

Yes, we have a wealth of talent and experience base that lets us do this, but it is really a jump forward.

Mr. LEWIS. Thank you, Dr. Keyworth. I don't think I have any more questions at this time, but I am pleased that you are so enthusiastic about the program and certainly we would be looking for your leadership and assistance in helping us to move forward in this area.

Dr. KEYWORTH. I assure you, you have that.

Mr. LEWIS. Thank you.

Thank you, Mr. Chairman.

Mr. BROWN. Mr. Packard.

Mr. PACKARD. Thank you, Mr. Chairman.

I, too, have enjoyed your testimony and your interest in this subject. I would like some clarification for my own information, and perhaps there are others that don't understand some of the differences in our terminology. What is the difference in hypersonic and

supersonic? What is the difference in high-speed transport and transatmospheric vehicles? I would like to know.

Dr. KEYWORTH. I am glad you asked that question. It is highly subjective. I will just define my own use of these terms.

I would say when we talk about supersonic, we are talking about numbers we are familiar with, mach 2, mach 3, possibly mach 4. When we talk about hypersonic, we tend to mean numbers of 10 and bigger, very high speeds. When we talk about TAV's, transatmospheric vehicles, we mean simply a vehicle such as the shuttle that can fly from the Earth through the atmosphere into vacuum, space, and return.

What is important here, Mr. Packard, is the ability to achieve very high altitudes and still be able to use the oxygen in the atmosphere, the residual oxygen in the atmosphere as the oxidizer, as a second fuel. That is the technological breakthrough that allows us to talk about flying at altitudes of higher than 100,000 feet, for example, and easily coast into orbit.

Mr. PACKARD. Thank you for that explanation.

With that, is it anticipated that the supersonic and TAV are separate goals or is it possible for those to be incorporated into a single vehicle? What, generally, are the options that we have in these areas?

Dr. KEYWORTH. That is what is so new and exciting. I think it is very possible to combine those two into a single one. The criterion that I believe we should be focusing upon is the economic leverage, economic feasibility. Is it possible, for example, for us to have a capability that performs what the shuttle does, that essential role that the shuttle plays today, and, at the same time provide commercial transportation for people wishing to fly to the Pacific Basin?

Astoundingly enough, and I could not have said this to you a year ago, I believe that it is possible to do that with one research and development program and one basic technology. Whether it is exactly the same craft, I can't give you an intelligent answer, but I can certainly say that it will be very similar.

Mr. LEWIS. Your alluding to the economic conditions leads me to my final question, and that is there is no question that funding will become a major issue in the progress that we make in these directions. No. 1, is the administration prepared to give the kind of support necessary—I am talking about financial support now—and what is the general attitude of the private sector in terms of a cooperative—and I speak again in terms of funding—a cooperative venture with the Government on this?

Dr. KEYWORTH. I will take them in reverse sequence, if I may. I think the private sector is very excited about this, is caught up in the same enthusiasm that I am attempting to reflect to you today. I think there will be a very vigorous commitment on the part of the private sector to capture this economic edge.

I would also say that, in spite of the fact that I have very much enjoyed many occasions with Chairman Brown recognizing my reawakened interest in science and technology, our administration has had a commitment since the day Ronald Reagan was sworn into office to ensure that this country has the strongest possible technology base. That is why we have virtually doubled the fund-

ing for our universities and basic research in universities in the first term.

What we have done is emphasize the need to spend wisely and carefully, recognizing that we are not, if you wish, made of money. Here is a virtually unique opportunity.

Mr. PACKARD. If the funding simply was not available to do all that we want to do in this area, would your priorities lead you to recommend that we move forward in the next generation of high-speed aviation or would you prefer to have limited funding earmarked for the leapfrog approach that you have identified?

Dr. KEYWORTH. I don't think this is a leapfrog approach. I think this is the next step. This is what present technology offers us. It is not necessarily more expensive than doing the interim step of a supersonic transport. It is a question of, as I said in my few prepared comments, whether we look forward or whether we attempt to bring the past into the present. That is the issue.

I am also not worried about whether the funds will be available, because if I am correct in my technical assessment and the assessment of others on this option, then I think the economic opportunities are so high that I have thorough confidence that our economic system will make certain that the funds are available.

Mr. PACKARD. Thank you, Dr. Keyworth. I appreciate and enjoyed your testimony.

Mr. BROWN. On that last point, Dr. Keyworth, probably the most exciting thing that you have said is to hint, at least, that we could improve the economics of transporting a load into space by two orders of magnitude. That alone saves several billion dollars a year and makes it worthwhile to invest a little money in something like this. That is completely in addition to the implications for maintaining our lead in global aeronautical transport which, again, would provide economic savings in the billions I am sure.

Dr. KEYWORTH. Thank you.

Mr. BROWN. I compliment you on recognizing this great opportunity.

Dr. KEYWORTH. Thank you very much.

Mr. BROWN. Thank you very much for being here.

Our next witness will be Mr. Crawford Brubaker, Deputy Assistant Secretary or Aerospace for the U.S. Department of Commerce. We are very pleased to have Mr. Brubaker here. Mr. Brubaker can qualify as a Californian, and Mr. Packard and I would both give him very high credibility because of that.

Mr. PACKARD. Absolutely.

STATEMENT OF CRAWFORD F. BRUBAKER, DEPUTY ASSISTANT SECRETARY FOR AEROSPACE, U.S. DEPARTMENT OF COMMERCE

Mr. BRUBAKER. Thank you, Mr. Chairman and members of the subcommittee.

The subject of the hearing today is one of great interest to me personally, to the engineers of our aerospace companies in particular, and to the traveling public in general.

I would like to follow Dr. Keyworth's lead and summarize my prepared remarks. I have given you a written statement for the record.

Mr. BROWN. Without objection, the full text will appear in the record.

Mr. BRUBAKER. High speed aeronautics has specific applications in the Pacific Rim, and I want to focus on the market needs for such aircraft. The idea of an Orient Express by air rather than by railroad certainly catches the imagination and opens the mind to all sorts of innovative ideas, especially if one has ever made that tedious 22-hour trip across the Pacific by air.

The Pacific Rim is a mixed region of economic development ranging from Japan and its galloping economy to Indonesia and Malaysia with newly developed industries. The Pacific Rim, for these purposes, we believe, includes the region bounded by China, South Korea, Japan, New Zealand, Australia, Indonesia, Thailand, and the west coast of the United States.

The distance between the Pacific Rim region and the markets to which these countries wish to export their products is huge. Current air transportation is considered fast and comfortable, but even so, the time to and from countries in the Pacific Rim is measured in 10 or more hours and across the Pacific in days if we start from this continent. So, no matter how comfortable the aircraft, it is still a long time to be confined in a tube in the sky traveling over water.

Surface transportation across the Pacific is, of course, much slower but is used to handle the cube required for shipment of large products. As the region develops, there will be more and more demand, in my opinion, for both surface transportation and air transportation.

The Pacific Rim is the fastest growing region of the world, the largest in land mass and population, and, most importantly, an area well known for profitability that it brings to foreign investment. In 1984, 8 of the top 25 U.S. export markets were located in the Pacific Rim. U.S. exports of $56 billion to this region accounted for 26 percent of our total U.S. exports; 9 of the top 25 suppliers to the United States in 1984 were Pacific Rim countries. They accounted for $119.8 billion or 35 percent of our total U.S. imports. The economic outlook for the Pacific Rim countries to the year 2020 is very attractive when compared to the rest of the world.

Rapid economic growth among the Pacific Rim nations and, as a consequence, the increasing demand for transportation has prompted a mounting interest in more efficient forms of air travel to the area. The International Civil Aviation Organization, [ICAO] in its 1984 annual report reveals substantial growth in international traffic in the Pacific. ICAO reported that Asian Pacific carriers accounted for 26.5 percent of international air travel in 1984 as opposed to 18.7 percent in 1975. This compares to a decline in the international air traffic carried on U.S. airlines which fell to 20 percent in 1984 from 22.1 percent in 1975.

Looking farther down the road, or perhaps I should say runway, Pacific Rim nations will account for an even greater share of world air traffic. For example, Pacific Rim air carriers which presently provide approximately 17 percent of total world air passenger service will likely increase their share to 20 percent by 1995. We expect most of this gain to result from growth in air traffic rather than from any significant increase in their share of the market.

The major constraint on air travel across the Pacific or across Asia to Europe is the time required. Extra crews must be carried, not to mention meal services, blankets, pillows, and fuel. This all cuts into passenger carrying capability of an aircraft used for such travel. And then, of course, there is jet lag, the normal additional price that a customer pays for such a trip.

Mr. Chairman, the economics of the region are exceptional. Japan is the economic nucleus of the region, particularly with regard to trade. Its economy accounts for more than 40 percent of the entire regional output, and that country has served as the growth center for the entire region.

The People's Republic of China accounts for one of every four people in the world and faces a substantial challenge to simply feed its population. Many reforms have been introduced, the results of which have led to substantial economic growth.

For example, since 1977, China has enjoyed an annual growth rate of over 6 percent, and some economists project a rate of nearly 5 percent annually for the remainder of the decade. Others, with incountry knowledge of China, project even higher growth rates, providing Government support for ongoing reform continues.

Taiwan, with less than 1.5 percent of the total population in the Pacific Rim, has exports to the United States of $16 billion in 1984 which was 33 percent higher than 1983. Our exports to Taiwan in 1984 amounted to $5 billion, up 9 percent over 1983. The Taiwan economy, incidentally, grew at 10.3 percent in 1984.

The ASEAN countries include Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Brunei. To these countries we have exported about $9.5 billion per year for the past 3 years on a yearly basis. Imports have risen from $11.7 billion in 1982 to $16.9 billion in 1984, a rise of 44 percent.

The ASEAN countries are among the most economically dynamic in the world. Together, they have a gross national product of more than $200 billion.

Exports to Hong Kong in 1984 reached $3 billion while the United States imports totaled $9 billion. Hong Kong's role as a gateway to China is certainly expected to become even more important. In recent years, China has become Hong Kong's fastest growing market, its largest supplier and leading destination, as well as a source for all its re-exports.

U.S. exports to Australia were almost $5 billion in 1984, up 25 percent over 1983, while imports from Australia reached $2.9 billion, also up 21 percent.

New Zealand, while not a major trading partner with the U.S., purchased only $708 million in U.S. products in 1984, and our imports were $880 million from New Zealand.

If the Pacific Rim continues on this growth pattern, and most economists predict it will, then there will be a need for a new type of air transportation.

The discussion among aircraft experts usually begins with the idea of a new generation high speed transport aircraft, and then the engineers mention the advances that have occurred since the Concorde was launched and the United States stopped its development of the SST 20 years ago. Suddenly, the discussion turns to the

concept of a 2½-hour flight from New York to Tokyo aboard a transatmospheric vehicle, and maybe Buck Rogers has returned.

But the concept isn't really science fiction. I think Dr. Keyworth has clearly identified that it is reasonable and practical. Propulsion systems have improved dramatically and high temperature metal problems have been solved. Computer navigation is simply a matter of course today. So, technically, the concept is valid, and the constraints may well be commercial.

As we approach the next century, new technology vehicles of transatmospheric type are envisioned with speeds up to mach 5.5 or even mach 10, with carrying capacity of 300 to 500 passengers traveling from New York to Los Angeles in 55 minutes and anywhere on the Earth in 2½ hours. They would operate from existing airports, use conventional fuels at lower altitudes, and incorporate engines using cryogenic fuels while flying above 100,000 feet.

Businessmen, as they look to the Pacific for new growth markets, now travel first or business class across the Pacific. With an understanding of the time that might be saved and the energy that would not be eroded by jet lag, many business passengers would transfer to a service that would cut their time across the Pacific dramatically. As the economies of the region improve, more and more of that traffic would be two-way rather than one-way and increasing the requirement on the lift for superclass runs. We all need to remember, of course, that travel time saved translates directly into lower levels of business expense.

With the projected buildup of the Pacific Rim economies and the accompanying increases in trade, there will be sufficient demand to meet operational costs of a very high speed Pacific Rim transportation system. Improved air transportation between the United States and the Pacific Rim countries offers a potential for welding long-term bonds between these trading partners. The region's dynamic growth and vast potential for development support a new goal for an expanded air transportation system.

Thank you.

[The prepared statement of Mr. Brubaker follows:]

UNITED STATES DEPARTMENT OF COMMERCE
International Trade Administration
Washington D C 20230

STATEMENT OF

CRAWFORD F. BRUBAKER
DEPUTY ASSISTANT SECRETARY OF COMMERCE
FOR AEROSPACE

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

JULY 24, 1985

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PACIFIC RIM COUNTRIES
AIR TRANSPORTATION OUTLOOK

The Pacific Rim is the fastest growing region, the largest in land mass and population, and most importantly, an area well-known for the profitability it brings to foreign investment. In 1984, eight of the top 25 U.S. export markets were located in the Pacific Rim. U.S. exports of $56.0 billion to this region accounted for 26 percent of total U.S. exports. Nine of the top 25 suppliers to the United States in 1984 were Pacific Rim countries, accounting for $119.8 billion, or 35 percent of total U.S. imports.

Of the top 25 countries with which the United States carried a trade deficit in 1984, seven were Pacific Rim countries and accounted for just over half of the total U.S. trade deficit of $123.3 billion. Japan alone accounted for $37.2 billion, or 30 percent. The economic outlook for the Pacific Rim countries to year 2020 is very attractive when compared to the rest of the world. It is unlikely, however, to match the very rapid growth experienced during the 1960s and 1970s, although individual country markets, such as China, should expand very rapidly in the future.

Pacific Rim, for present purposes, includes the region bounded by China, South Korea, Japan, New Zealand, Australia, Indonesia and Thailand. The table below lists the gross domestic product (GDP), the population, and the national debt of the major Pacific Rim countries. These countries together account for 21 percent of the world gross domestic product, 37 percent of the population and 10 percent of the debt. By comparison, the United States has 29 percent of the world gross domestic product, 6 percent of the population and 10 percent of the world debt.

PACIFIC RIM COUNTRIES
KEY STATISTICS

Country	GDP (Billions of U.S. Dollars) 1984	Population (Millions) 1984	National Debt (Billions of U.S. Dollars) 1982
Japan	1,236	121	114
China	360	1,039	5
Australia	165	15	--
Indonesia	82	158	26
South Korea	83	42	39
Taiwan	51	20	9
Philippines	29	53	21
Thailand	38	51	14
Malaysia	32	16	10
New Zealand	21	3	10
Hong Kong	21	5	--
Singapore	18	3	2
Total	2,205	1,526	250

Rapid economic growth among the Pacific Rim nations, and as a consequence, the increasing demands for air travel, have prompted a mounting interest in more efficient forms of air travel. The International Civil Aviation Organization (ICAO) 1984 annual report reveals substantial growth in international traffic in the Pacific. ICAO reported that Asia/Pacific carriers accounted for 26.5 percent of international air travel in 1984 as opposed to 18.7 percent in 1975. This compares to a decline in the international air traffic carried on U.S. airlines, which fell to 20 percent in 1984 from 22.1 percent in 1975.

Looking further down the road, or should I say "runway", Pacific Rim nations will account for an even greater share of world traffic. For example, Pacific Rim air carriers, which presently provide approximately 17 percent of total world air passenger service, will likely increase their share to over 20 percent by 1995. We expect most of this gain to result from growth in air traffic rather than from a significant increase in Pacific based airline market shares.

The present chief stimulus behind the growth in air traffic in Pacific Rim countries comes from the rapid economic development that has occurred with the industrialization of the more aggressive countries in the region. Most of these developing countries are economically immature with large rural populations. The regional diversity is considerable when viewed from the perspective of race, language, religion, political system and ethnic composition.

In 1983, the Pacific Rim countries accounted for 37 percent of the world's population. The region's population growth is forecast to be 2.2 percent annually during the 1980s compared with the world average of 2.0 percent.

The world recession reached the Pacific Rim countries in 1982 and most real growth rates fell by several percentage points. However, elements of the region's past superior economic performance remained in place, and Pacific Rim economies are benefiting substantially from the present world upturn.

The recession took a particularly severe toll on the highly trade-oriented Pacific Rim countries. Thus, as world trade expansion slowed from an annual rate of 10 percent to one of virtually no growth, the impact on trade-oriented economies was substantial. The slowdown cut exports of manufactured goods (affecting Japan, South Korea, Taiwan, Hong Kong) and commodities (affecting Australia, Indonesia, Malaysia) alike.

Japan is the economic nucleus of the region, particularly with regard to trade. Its economy accounts for more than 40 percent of all regional output, and the country has served as the growth center for the entire region. The long-term outlook for the Japanese economy remains optimistic. In 1984, the U.S.-Japan trade deficit surged to a record $36.8 billion, an increase of almost 70 percent over 1983. Japan continues to enjoy an economic recovery which began in 1983. For the period 1983-1993, growth of the Japanese economy is projected at 3.4 percent, considerably higher than the 2.8 percent rate for North America and the 2.6 percent rate for Western Europe.

The People's Republic of China accounts for one of every four people in the world and faces a substantial challenge to simply feed its population. Many reforms have been introduced, the results of which have led to substantial economic growth.

Since 1977, China has enjoyed an annual growth rate of over 6 percent, and some economists project a rate of nearly 5 percent annually for the remainder of the decade. Others,

with in-country knowledge of China, project much higher growth rates, providing government support for ongoing reform continues. In 1984, U.S. exports to China amounted to $3 billion and imports from that country stood at $3.4 billion.

Taiwan, with less than 1.5 percent of the Pacific Rim total population, had exports to the United States of $16 billion in 1984, up 33 percent over 1983. U.S. exports to Taiwan in 1984 amounted to $5 billion, up 9 percent over 1983. The Taiwan economy grew 10.3 percent in 1984, fueled by an increase in Taiwan's exports. Almost half of these exports were sold in the U.S. market. Taiwan continues to develop its domestic electronics industry and encourages the automation of other key industries such as machine tools.

The ASEAN countries make up the remainder of the Pacific Rim countries and include Indonesia, Malaysia, the Philippines, Singapore, Thailand and Brunei. U.S. exports to these countries over the three years 1982-1984 have remained at about $9.5 billion each year. Imports have risen from $11.7 billion in 1982 to $16.9 billion in 1984, a rise of 44 percent.

The ASEAN countries are among the most economically dynamic in the world. Together, they have a gross national product of more than $200 billion. These countries have skilled work forces, an abundance of natural resources, and aggressive economic policies. ASEAN countries will continue as major suppliers of key raw materials -- petroleum, rubber, tin, other metals, palm oil, and hard fibers -- to industrialized countries. A broad range of manufactured goods, including textiles, electronic components and consumer goods will continue to be imported into the United States from the region.

Exports to Hong Kong in 1984 reached $3 billion while U.S. imports totaled $9 billion. Hong Kong's role as a gateway to China is expected to become even more important. In recent years, China has become Hong Kong's fastest growing market, its largest supplier, and leading destination as well as source for its re-exports.

U.S. exports to Australia in 1984 were almost $5.0 billion, up 25 percent over 1983, while imports from Australia reached $2.9 billion, also up 21 percent. Exports over the next 10 years to Australia will consist primarily of electronic and capital equipment. Australia will continue to exploit their natural resources, particularly petroleum, uranium, bauxite, copper and diamonds.

New Zealand is not a major trading partner with the United States, purchasing only $708 million in U.S. products in 1984. U.S. imports from New Zealand in 1984 amounted to $880 million.

World international air traffic revenue passenger miles is forecast to grow at an average of 7 percent annually from 1984 to 1990. Average annual regional growth will range from 5 percent for the United States and Europe to over 7 percent for the Middle East and Pacific. The optimistic economic outlook for the Pacific Rim justifies projections for strong growth in air traffic for that region. The Pacific share of total world traffic is projected to grow from 18 percent in 1987 to 21 percent in 1997. There is reason to believe that sustained air traffic growth for the Pacific Rim countries will continue well into the next century.

Based on current expectations, the U.S. trade deficit could increase over 20 percent in 1985 to $150 billion from $123 billion in 1984. Pacific Rim countries will probably continue to account for about half of this increased deficit.

A large variety of U.S. manufactured goods are meeting stiff competition, both domestically and in export markets, from foreign-made quality products offered at extremely competitive prices. Lower foreign labor rates contribute significantly to the lower prices. For example, at P.T. Nurtanio, the Indonesian government aircraft factory, company engineers average $500 per month and junior engineers draw about $200 monthly. Middle technical school graduates, the bulk of the work force, earn $65 to $70 per month, and those who are in company training programs draw 80 percent of these amounts. By comparison, the average earnings of a U.S. aircraft production employee, although generally more productive, is about $2,180 per month.

The transfer of more U.S. manufacturing, industrial know-how, and accompanying technology to Pacific Rim countries is inevitable. Offshore sourcing, offshore investment; creative alliances; joint ventures; and stepped up marketing efforts will be required to be more competitive in international markets. Such efforts are indicative of major trends already underway in the United States thereby creating an increasing demand for international air transportation.

U.S. trade with the Pacific Rim community has grown by 75 percent within the last six years, accelerating well beyond the volume of trade with Europe. Mutual defense linkages are also of increasing significance. Strategically and economically, U.S. trade and alliances in the Pacific have

major implications for the future. Improved air transportation between the United States and the Pacific Rim countries offers the potential for welding long-term bonds between these trading partners. The region's dynamic growth and vast potential for development should support an expanded air transportation system.

Existing types of air cargo aircraft should prove adequate to meet Pacific Rim country requirements through the end of the century. But the travel time between these countries and their major trading partners (United States and Europe) with current subsonic aircraft results in passenger frustration.

Air travel from the United States to Europe by subsonic aircraft takes at least seven hours. This time is reduced to less than four hours on the supersonic Concorde. By comparison, passenger travel from the United States to the Philippines, located near the center of the Pacific Rim countries, requires about 22 hours or, if a long range Concorde were available, about 10-12 hours.

As we approach the next century, new technology transatmospheric vehicles are envisioned with speeds up to Mach 5.5 carrying 300-500 passengers. These aircraft could travel from New York to Los Angeles in 55 minutes and to any point on earth in 2 1/2 hours. They would operate from existing airports, use conventional fuels at lower altitudes, and incorporate engines using cryogenics fuel while flying at about 100,000 feet.

Development of such an extremely high speed transport will probably require sources of multi-national risk capital. Sources of funds would likely include inputs from multi-national industries, airlines, institutions and private investors.

On the consumer side, travel time saved translates directly into lower levels of business expenses. Concorde passengers are 70 percent business executives and lawyers - half use it more than four times a year with considerable savings in business costs.

In conclusion, I would like to quote Dr. Jay Keyworth, the President's Science Advisor, at a press Conference on April 1, 1985:

> "...there's still enormous potential and...continued R&D can lead to monumental improvements in the performance of aircraft in coming decades."

> ...national R&D efforts must emphasize the smooth interaction between basic research and technology development in order to create the low of new knowledge needed for practical and affordable breakthroughts in aeronautics. Progress toward this objective will be dependent on how effectively we take advantage of the closely coupled industrial bases shared by the military and civilian sectors. ...with the continued growth of aeronautics toward the transatomospheric region, there will be increasing overlap between traditional aviation technologies and those needed for space transportation and operations."

With the projected build-up of the Pacific Rim economies and accompanying increases in trade, there will be sufficient demand to meet operational costs of a very high speed Pacific Rim transportation system.

Mr. BROWN. Thank you very much, Mr. Brubaker.

Your statement does give us a very sound and important evaluation of the market development potential in the Pacific Rim, and that is extremely important to our consideration. There is, however, the fundamental economic question which remains and which was the bane of the Concorde, and that is the matter of cost per passenger mile and what the ultimate results are in terms of cost of a ticket to exploit that very high speed.

That is one of the questions, and at some point, you are going to have to make some computations as to what the operating expense of a mach 5.5 plane carrying 300 to 500 passengers is so that we can begin to compute some of these things. You, I presume, have not yet arrived at any definitive figures of that sort, but have you made any projections based upon possible scenarios in that regard.

Mr. BRUBAKER. As you said, we have not calculated those figures at this point. We think it is a little premature to do that, but the reason we talk about 500 passengers is because that is the kind of a load that would be economically viable and would bring the ticket prices, we think, down within reason. That is why we are looking at a vehicle that we would hope would handle a large load.

One of the Concorde's problems, as you probably know, in cost per seat-mile is that it is a relatively small aircraft and could not, therefore, justify the costs of operation.

Mr. BROWN. Of course, the exciting thing, as I mentioned, in Dr. Keyworth's testimony is that he surfaced this potential at least of a two order of magnitude reduction in the cost of transporting a pound of cargo into space. Obviously, that kind of a figure would not be available for transport on Earth, but something almost as exciting might be possible, and we will need to look at those figures or the possibilities of such figures at an early date in order to really have a comprehensive picture of what is possible here.

There is one other aspect, at least one other, which I hope somebody is giving consideration to. It takes you an hour to get out of the airport today and to get into the airport. It is going to look rather incongruous to spend several hours on the ground for a 55-minute flight from New York to Los Angeles or a 2-hour flight from New York to Tokyo or wherever. That, of course, leads to the question of whether some thought is being given to coordination of systems required to improve these capabilities also which may require, for example in international travel, onboard processing of documents for the travelers or, conceivably, onboard inspection of baggage and things of that sort.

Is there someone in this vast panoply of people giving consideration here who is thinking about the total systems concept here so that we can look at a complete picture of what may be available?

Mr. BRUBAKER. Mr. Chairman, it has not escaped my own attention relative to this problem of how do you get in and out of an airport faster, but I do want to say that the airports and airways of this world are really involved with our FAA and not with my part of the Commerce Department. It is my understanding the aircraft we are talking about would take off and land at conventional airports.

We need to look at ground systems and ground handling and I agree with you, a total system examination is certainly warranted.

Mr. BROWN. Mr. Packard, do you have any questions?

Mr. PACKARD. I have but one, Mr. Chairman. Thank you.

Obviously, Mr. Brubaker, the undertaking of such a project and program is going to be fraught with all kinds of hurdles to overcome. Do you see as the major hurdles to accomplish the goals that have been outlined this morning to be technology, to be funding, or to be the ability to coordinate the necessary effort to get the job done? Where do you see the major stumbling blocks?

Mr. BRUBAKER. I believe what we need is the development of a public demand for this kind of effort. Hopefully, these hearings will be the start toward that end along with the report which Dr. Keyworth and his office issued several months ago. I happened to serve on that committee, and I agree with the report. The purpose was to set us some goals so that we could indeed obtain a consensus and move forward toward solving those kinds of problems.

Mr. PACKARD. Do you see a national commitment as our major concern?

Mr. BRUBAKER. Yes, I do.

Mr. PACKARD. I won't go further. Thank you, Mr. Chairman.

Mr. BROWN. Mr. Nelson.

Mr. NELSON. Thank you, Mr. Chairman.

First of all, Mr. Brubaker, let's get for the record the role of the Department of Commerce in what is otherwise an airline or transportation issue that would normally fall under the jurisdiction of the Department of Transportation. Why don't you state for the record why you are so enthusiastic about this.

Mr. BRUBAKER. Well, I am enthusiastic because I believe it is a problem which will be solved by some mode of transportation or another, and I am very interested that that mode of transportation be provided by the aerospace industry. Since I have the portfolio for the aerospace industry in the Department of Commerce and the manufacturers involved therein, I want that business in that industry.

Mr. NELSON. So, you are saying from the standpoint of U.S. industry, you want that there.

Mr. BRUBAKER. That is right.

Mr. NELSON. What about from the standpoint of access of the United States to the Far East where, presumably, with this kind of technology of a mach 5 couple of hours to Peking, you are going to look at a lot more traffic that is going to be going with that kind of technology available.

Mr. BRUBAKER. Yes; and I think that is going to take place because of the demand for the economy and the growth in those areas. The increased transportation requirement is going to be there regardless. What this does for us is cut down on actually the total amount of traffic because we are not doing it with subsonic smaller aircraft. We are doing it with supersonic or transonic and large aircraft. I think that will make a significant difference in payloads and passengers into those countries and therefore make the access a feasible one.

Mr. NELSON. If you were from the State Department, I would ask you the foreign policy implications.

Mr. BRUBAKER. I am not from the State Department, so——

Mr. NELSON. If you were, I would ask you if we had less than 2 hours from New York to Peking, what that would do to our foreign policy in opening up all the more the increasingly warm relationship between China and the United States. That might be a possibility. If you were from the State Department, I would ask you that.

Now, since you are from the Commerce Department, answer this. Why haven't the manufacturers, the potential manufacturers of this Orient Express, why haven't they been stepping forward actively campaigning for airline support for this mach 5 aircraft?

Mr. BRUBAKER. I think the McDonnell Douglas representative who will appear here this morning to testify probably could answer that question better than I. I have only been in the Government for the past 21 months rather than in an aerospace firm, but I was with Lockheed during the period when the U.S. commercial SST was under consideration. My personal opinion is that the aerospace companies would like to have at least some public opinion on their side before they put any significant efforts or moneys into the new high speed technology aircraft concept.

That is not to say they have ignored high speed transport aircraft design since 1972. I do not believe they have. On the contrary, each of the airframe and engine companies that I have contacted have continued to look at and work on the challenges presented to them by the high speed commercial aircraft, and they could, in all probability, commit a design to production if the public interest and adequate investment and enthusiasm were there.

Mr. NELSON. All right. Let's talk about the public interest. Why haven't we seen a public interest more vocal about faster travel across the Pacific?

Mr. BRUBAKER. Well, that is a difficult question for me to answer. I am not a Gallup poll analyst. I can give you some thoughts of my own on it.

I believe that for some reason or another technology advancement, at least in the aircraft side of the business, had a bad reputation during the sixties and the seventies. I think that the public attitude is starting to change and that the technology challenge will be what changes it. We will see an appropriate goal for the United States not unlike the walk on the moon goal.

Mr. NELSON. Now, from your perspective as the Department of Commerce, what would happen if the U.S. manufacturers failed to pick up this technology? What would be the effect on, your opinion, as to the effect on U.S. aerospace firms and, secondly, upon U.S. business interests generally and, thirdly, upon the traveling public?

Mr. BRUBAKER. I think the first effect would be that we would lose our technological edge in the world aerospace business. As Mr. Lewis pointed out, the British are already looking at horizontal takeoff and landing, supersonic kind of aircraft and engine. They have closed, I understand, that engine to any outside look-see so they think they really have a breakthrough. We have to stay ahead in technology.

The strength of our industry has been because it has stayed ahead in technology. If we do not do that, then I think we run the risk of losing that marketplace. For your information, over the last 5 years the aerospace aircraft industry in the United States has

had a surplus export trade balance of around $14 billion average per year.

Mr. NELSON. In recent years?

Mr. BRUBAKER. In the last 5 years. Last year was $10.5 billion. This year it will be over $14 billion.

Mr. NELSON. And no telling what it could be if we just——

Mr. BRUBAKER. No telling what it could be if we lead the way in this kind of an aircraft.

Mr. NELSON. All right. Just a couple of quickies here. Can present airports—perhaps you are not the right one to ask this to, but at least let me get it out on the record—can present airports handle a mach 5 aircraft?

Mr. BRUBAKER. Our understanding is that the technology currently being looked at would allow the aircraft to land and take off from conventional airports.

Mr. NELSON. Then, what would it cost us to develop such an aircraft? Do you think that its potential commercial viability working in that Orient Express or Pacific Rim, whatever you want to call it, is it going to be commercially feasible after you spend that kind of development cost?

Mr. BRUBAKER. Yes, I believe it will be commercially feasible after we spend the development costs. The development cost is going to have to be ahead of the actual commercial venture.

Mr. NELSON. Thank you, Mr. Brubaker.

Thank you, Mr. Chairman.

Mr. BROWN. I would like to call now on Mr. Glickman who was the one largely responsible for setting up this hearing and who has long been interested in the subject matter and is prepared to provide some of the enthusiasm necessary to move it forward.

Mr. Glickman.

Mr. GLICKMAN. Thank you, Mr. Chairman. I want to thank you for calling the hearing and apologize to the witnesses for not being able to be here earlier. We have the farm bill in markup right now, and I am going to have to run back pretty soon.

I would just like to make a couple of brief points. One is that I am excited that you, Mr. Brubaker, and Mr. Keyworth indicate that there is an administration interest in doing more than just talking about hypersonics. It appears to me that we have been stuck in aeronautics for the last 20 years and there really are no advances occurring of really what I call quantum leap advances. We are making what I call incremental advances in aviation, especially in commercial aviation.

Now is the time to move, but it will require a great deal of up-front money on behalf of both the Government and the private sector, or else it just will not happen.

One of the problems that I have always had with respect to NASA and I think one of the reasons why we have tended to perhaps overemphasize the space side of NASA and underemphasize the aeronautics side of NASA is because we have split them, and really they ought to be together. After all, the space shuttle is really an airplane coming back to Earth from space.

What we have here in the hypersonic area is an airplane with space applications to it. What we have done in America both in the private sector as well as in Government is split the subjects up. It

doesn't make any sense. This whole thing may be an example of how NASA ought to be internally looking to combine those functions again. The same thing is true in the private sector in order to get the great amount of impetus to the combination of aeronautical and space related engineering and technological feats that are necessary to move this thing ahead.

So, I would hope that from not only your perspective, but Keyworth and whoever else is here from NASA and the other agencies that more than lip service be given to this issue, because this is truly the leapfrogging issue for aviation into the fast field, but also recognize that it takes an enormous financial commitment and it probably will take some joint commitments between us and the Japanese and others. I am not sure we are going to be able to do this all by ourselves.

Would you agree with that or how do you feel about that?

Mr. BRUBAKER. I would hope we could do it by ourselves because the economics involved in it—the payoff is so good, I think, that if we don't do it by ourselves we are missing a real package. On the other hand, if other reasons cause us to have to have partners, that certainly is a possibility, and the pot may well be big enough to share with somebody. But I would prefer to see us do it ourselves if we can.

Mr. GLICKMAN. Do you see any evidence to date that the private sector and/or the Government is pushing ahead aggressively enough to do it by themselves?

Mr. BRUBAKER. We still need to move ahead further than we certainly have so far, but I think the evidence over the last year or year and a half, including the work done by Mr. Keyworth's group, shows that there is indeed an interest in moving ahead.

I would agree with what you have said. There is no question in my mind that time has now come to join together the aircraft side and the space side and take advantage of a lot of the investment we have made in the space side and put it into the aircraft side of the business. That would be a payoff that we can get right now on investment that has been made over the past 20 years.

Mr. GLICKMAN. You see, one of the things I have always felt about the shuttle is that the shuttle was not as good as it could have been because it was designed by the space people and that it didn't have the appropriate institutional aeronautical components in it. So, we have had problems with tiles. We have had problems with design. I am not saying the shuttle isn't good. It is good, but it was designed for space in mind, not to land, not to be an airplane in mind.

This hypersonic gives us an appropriate vehicle to do both, and it may be a good opportunity both for the private sector and NASA. I would just encourage you to keep on this, to pursue it. It is an advancement for America that I think will help us commercially as well as scientifically but the impetus will have to come from the economic incentive and that is where your office comes in, because you are the point man between the private aviation companies and the Government.

So, I thank you for being here. I also want to thank you and compliment you for your aggressive work in aviation for this Government.

Mr. BRUBAKER. Thank you, sir.

Mr. GLICKMAN. Thank you, Mr. Chairman.

Mr. BROWN. Mr. Reid.

Mr. REID. Mr. Chairman, I had two other committee meetings, both chaired by the chairman of the full committee, but the subject matter of this was so interesting that I broke away from both of those committees to come here and look over the testimony given by Dr. Keyworth and you, Mr. Brubaker, and I hope to be able to hear some of the other.

I really congratulate you, Dan Glickman, for the work that you have done in this area and also you, Chairman Brown, for having this hearing. I think this is really exciting and is something that we really have to look forward to in the future.

My only statement I would like to make, and I wish I had had the opportunity to talk to Dr. Keyworth and ask him some questions is, Mr. Chairman, it appears to me that Dr. Keyworth's statement, and I really admire his scientific background and the work that he has done, but too often his testimony is simply that he has appointed a committee and they are going to look into something. I find that there is very little done other than these committees being appointed. I would like to see, frankly, some more resources put toward some of these programs that Dr. Keyworth talks about, this being certainly one of the many things that he talks very favorably about that I see too little action.

I would, Mr. Chairman, again state that I think by holding these hearings and by this committee being involved with this, maybe we can get the ball moving a little more rapidly.

Mr. BROWN. Thank you, Mr. Reid.

Does anyone else care to ask any more questions of Mr. Brubaker? [No response.]

Thank you, Mr. Brubaker, very much for your testimony.

Our next witness is Dr. Charles Buffalano, Acting Director of DARPA in the Department of Defense. I would like to note that Dr. Buffalano is Acting Director of an agency which was headed by Dr. Cooper for some period of time and with whom we have worked in the past.

We have always held a very high regard for the agency and the fact that it has sponsored research in a number of areas which have tremendous significance not only to the military to the community but to the civilian community as well. It has been at the cutting edge of many things which have proven to be of very great value to the total national interest.

We welcome you here this morning, Dr. Buffalano, and you may proceed with your testimony.

STATEMENT OF DR. CHARLES BUFFALANO, ACTING DIRECTOR, DEFENSE ADVANCED RESEARCH PROJECTS AGENCY, U.S. DEPARTMENT OF DEFENSE

Dr. BUFFALANO. Thank you, Mr. Chairman.

Carrying excitement this morning appears to be the same as carrying additional coals to New Castle. Let me say that I would like to carry my share. We are excited, and it is a great pleasure for us to appear before you this morning to talk about the development

program which DARPA is engaged in and to talk to you in detail about some of the technologies which we have been batting around.

We feel that this is an exciting and challenging program, and we have been working on the technical tall poles for an aerospace plane.

In order to save time and get right to it, I would like to ask to have my prepared statement read into the record.

Mr. BROWN. Without objection, so ordered.

Dr. BUFFALANO. And to introduce to you, as you already recognized, Dr. Robert Cooper, and mention that he is still affiliated with the Department of Defense as a consultant to the Office of the Secretary. I have also asked Mr. Robert Williams who is the program manager for this program to join us this morning and to give us that special briefing.

It is a pleasure, again, to be here.

Robert, would you do the deed?

Mr. WILLIAMS. Thank you, Mr. Chairman, for this opportunity to appear before this committee.

I would like to say at the outset that my introduction into this technology began along the lines that Dr. Keyworth was referring to. At about the age of 10 in the early 1960's I read a book, "Skyrocket Into the Unknown," about a test pilot by the name of Scott Crossfield breaking mach 2, and that was my first book on aviation. I haven't deviated much from the enthusiasm of that course.

We are indeed about an extremely exciting new era or perhaps a renaissance in aerodynamics, aerospace. In keeping with DARPA's congressionally mandated charter to exploit those emerging technologies which have major potential for this country, we have initiated a technology activity for a new class of hypersonic aircraft, and we believe its time is just about here from a technology standpoint.

We call this new technological concept—the idea is not new, I might add. The aerospace plane has been bandied around by those of us who have been fascinated by aerospace for many years. We believe that it embodies technology for our country's future. We would like to tell you about that program today.

What we envision at DARPA is an airplane which could take off from a conventional airfield and have cruise speeds on the order of 4,000 to 8,000 miles per hour which could have application both to the civil sector along the lines which Dr. Brubaker was referring to as well as for military purposes. In addition to being an aircraft, we believe that this concept could also bypass the separate concept of a rocket plane and in fact become a space plane with payload to orbit cost on the order of one one-hundredth of today's launch systems.

This indeed is the concept which Mr. Nelson and Mr. Glickman have alluded to earlier of perhaps combining the technologies into a single vehicle.

The flight envelopes of this vehicle would embrace those of current technology where you see here very graphically the altitude of air-breathing aircraft versus their mach number, the times speed of sound of the aircraft, operating both as an aircraft, as an airplane at speeds of perhaps as high as mach 12 and, additionally, in

an acceleration mission to actually accelerate the vehicle into space orbit.

We, at DARPA, are investigating those enabling technologies which could permit this kind of a vehicle to come into being. These include the use of liquid hydrogen or perhaps methane for endoatmospheric operation, new concepts in ramjet/scramjet propulsion capable of operating at extreme hypersonic speeds, and other technologies such as high temperature materials, cryogenic fuel tanks, and efficient utilization of the hydrogen that would be used as a fuel and the advancements in avionics which are emerging at the present time.

A ramjet, as its name implies, uses the ram air pressure resulting from the forward motion of the vehicle to provide jet engine compression. It has neither the compressor nor the turbine of a turbojet engine. It normally cannot produce thrust at low velocity since speeds of several hundred miles per hour are required to get the needed compression.

A ramjet inlet slows down the incoming air while compressing it and then burns the fuel as you see on the lefthand figure. It burns the fuel in the air subsonically in what is called a subsonic compression technique and exhausts the compression products through a nozzle to produce thrust. However, at speeds above mach 4—and we frankly do not know the upper limits of air breathing speed to date, but they are going to be very, very high, unprecedentedly high—in order to fly faster, the flow and the internal geometry is varied in order the allow the air to remain at supersonic speeds throughout the combustor. This is called a supersonic combustion ramjet, and we believe it has potential for mach 12 or even higher.

The primary emphasis of DARPA's hypersonic technology program is the development of ramjet/scramjet propulsion capable of operation to these very high speeds. There are a number of interesting and highly challenging technical barriers associated with such a propulsion system, but none of them appears to be insurmountable to us today.

The technology being explored by DARPA would enable the propulsion engines to cover three different regimes, that is, to take off, to fly at hypersonic speeds, and to rocket into space. Such a system of propulsion engines would have to be carefully integrated with the airframe. Proper integration of the inlets into the aircraft engines is a critical design problem because the shape of the airframe itself determines, in large part, the performance of the engine.

The potential performance of such an engine is best described by a parameter known as the average specific impulse—ISP—which is a measure of the pounds of thrust from the engine per pound of fuel flow through each second. This measure has as its unit seconds, and the larger it is, the more efficient the propulsion may be.

Over the speed range of mach 0 to mach 25 which is the speed required to insert into orbit, the various engines could have an average specific impulse of as much as 1,200 to 1,500 seconds. This compares with an impulse of only 470 seconds for the best hydrogen-oxygen rocket engines such as are currently used in the space shuttle and does not also consider the much reduced specific impulse of the solid boosters for the space shuttle which is about 230 seconds, perhaps 250 seconds.

It is the much higher specific impulse, the much more efficient fuel utilization of this type of engine which gives it the possibility of a single-stage horizontal landing and takeoff vehicle which could also be both an aircraft and a spacecraft. Here, we have the name aerospace plane. We have indeed, Mr. Glickman, merged those two technologies in the way that you have alluded to.

In the lower speed range, the average specific impulse is even larger than the numbers I have quoted, thus making the scramjet engine attractive for an earth-to-earth transportation system such as your committee is exploring today. The fact that the propulsion system is comprised of several similar or identical modules makes it possible to develop and test full-size engines in ground test facilities from simulated flight speeds of zero to perhaps mach 12 with full replicated conditions of perhaps mach 8.

In another area, we are investigating the concept—let's see—I wanted to give you just a brief note of history here, Mr. Chairman, about the background of scramjet propulsion.

In the 1960's, the Air Force, the Navy, and NASA invested heavily in research and development of hydrogen-fueled scramjet engines. Both the Air Force and the Navy terminated their hydrogen fueled scramjet research when NASA's Mercury, Gemini, and Apollo programs selected and developed hydrogen-oxygen rockets for space launch as opposed to air breathing systems.

Rockets were the first propulsive means used in supersonic and hypersonic flight. Both the X-1 research aircraft, the first aircraft to break the speed of sound, and the X-15 and, indeed, the Douglas skyrocket which Scott Crossfield flew were the first planes to fly at hypersonic speeds and were powered by rocket engines.

The physics of rocket operation was well understood at that time. Furthermore, rocket technology was more mature. Intercontinental ballistic missiles and air to air missiles used rockets at the time. While subsonic combustion ramjet technology was fairly well understood and some ramjets were used in operational missiles, such as the Bomarc and the Talos missiles, the understanding of supersonic combustion phenomena was in its infancy at the beginning of the space age.

In addition, rockets could be completely developed and tested on the ground and their performance accurately determined at any speed in the atmosphere or space. Therefore, rockets were naturally the first engines to be used in the race for space.

What occurred, however, was that during this period, the people at the National Aeronautics and Space Administration, or I suppose then the NACA at the outset of this work and then becoming the NASA—investigated the use of scramjet propulsion for an air-breathing aircraft with very high ISP performance. The engine shown here is called a regeneratively cooled engine suitable for application to the X-15 aircraft.

In addition, the Air Force also investigated ramjets. This one shown was called the alligator engine because of its snout. This engine was also tested at very high speeds in ground base test facilities. We never quite made it to flight test of the hypersonic research engine on the X-15. That program was terminated at the time this country turned its eyes toward space.

In addition to the hydrogen-fueled ramjets, DARPA is also developing propulsion technology for combined cycle engines called airturboramjets and cryojets. The airtuboramjet you will hear about from the Aerojet people this afternoon, so I won't dwell on it, but just tell you that what it does essentially is to obviate the technological limitations of high turbine temperatures by going with what we call a cooled turbine. The turbine is not exposed to the ambient air. It doesn't see the high temperatures that a normal turbojet engine would.

So, this provides another attractive option for developing take-off capability up to speeds on the order of mach 5. Indeed, with the advent of new materials technology, it could perhaps go beyond that.

The other key technologies for an aerospace type plane involve the use of strong, lightweight, high temperature materials, advanced aerodynamics, advanced propulsion, and efficient hydrogen utilization. I would like to briefly speak to each of these subjects at this time.

In the advanced aerodynamics area perhaps the major breakthrough and precisely what you mentioned before, Mr. Brown, is the advent of supercomputers and their utilization to compute the complex flows. Here, we have examples at work at the NASA Langley computing flows on the inside of supersonic combustion engines. Here are calculations on the outside. In this case, you see the space shuttle where we are actually calculating in this multicolor ray tracing technique the streamlines of flow about a hypersonic body.

Finally, to back these advances in supercomputers up we have developed experimental techniques and measurements of the captured flow fields around the aircraft and into the engine. Here you see a shock wave emanating from the forebody of a supersonic combustion ramjet vehicle being captured by the air inlet of the engine where the needed engine air compression takes place.

Another technology area is that of long life materials. The advances which have taken place in this area are truly astounding and have major import to this country. One of them which we at DARPA are very proud about is called carbon-carbon technology, the next generation. As you may know, the space shuttle utilizes carbon-carbon on both the nose and the leading edges. At DARPA we, in conjunction with the people at the Vought Corp., have engaged in research to push that technology another generation.

This picture shows a turbine made entirely out of carbon-carbon material which we have spun at speeds on the order of 40,000 rpm. This is an unprecedented accomplishment in the field of composite materials for turbine applications, and we are very proud of that.

Another significant breakthrough being pursued broadly in the United States and indeed in the Soviet Union as well is the rapid solidification rate technology wherein minuscule particles of material such as titanium in a molten state are dropped on a spinning wheel, slung out from the wheel and cooled at rates on the order of 1 million degrees per second. It is really fascinating and it locks in crystalline properties of the material resulting in the very high strength and high temperature capabilities of those materials.

Another technology which is required—this is not really materials technology but is appropriate for thermal control—is hydrogen cooled engine structures. Here what we are addressing is areas where passive materials will not solve the problem, one can in fact use the unique cooling properties of hydrogen using the fact that it is a tremendous heat sink and use that to actively cool engine and airframe structures. This is work being done again at the NASA Langley Research Center.

An area which is very key to the aerospace plane technology is the efficient use of hydrogen. Hydrogen, as you may be aware, has some very unique properties. It holds the promise of achieving independence from foreign petroleum resources. It can be easily made from steam reformation of natural gas or it can be made from water by electrolysis or photolysis techniques and any other energy source such as fossil, nuclear, solar, or biomass.

Hydrogen combustion is nonpolluting because its combustion product is indeed water, and water does not endanger the ozone layer. Contrary to the misconceptions surrounding the Hindenburg disaster, hydrogen is actually a safer fuel than gasoline in that it burns with a nonpropagating flame. Hydrogen rapidly dissipates in the atmosphere due to its extreme lightweight which means that it does not tend to collect or form a concentrated cloud that could be ignited explosively. It floats up rather than out, if you will.

Hydrogen also offers some advantages to aircraft operation. Hydrogen would have a lower gross weight in hydrogen aircraft because of the low specific gravity in its liquid state and thus perhaps a lower cost. Finally, as fossil fuel supplies become outdistanced by the increasing demands, hydrogen may be expected to eventually become less expensive than petroleum fuels.

DARPA is exploring some of the key technologies needed for widespread use of hydrogen as a fuel, and some of these are shown in the next chart, particularly as applied to aircraft. Liquid hydrogen has the most energy per pound of any fuel, on the order of three times as much as a hydrocarbon, and it is used both as a fuel and as a coolant because in those regeneratively cooled structures I alluded to, the hydrogen can be used to absorb the heat and then become a gaseous state as it changes state from liquid to gas and injected into the engine.

It can also be used for other things. For example, one can use hydrogen very efficiently to manage larger payloads by using it to cool the crew payload compartment, by using it to propel the rocket thrusters rather than carrying along separate rocket thruster fuels, to use it for a thing we call a solid oxide fuel cell. This is a development being done by the Argonne National Laboratories for DARPA which we are quite excited about.

It is, if you will, a ceramic semiconductor technology. By microminiaturizing ceramics, one is able to put air on one side of a honeycomb and fuel on the other. Call that hydrogen and oxygen, if you will, for this example. Then, by an interesting electrochemical reaction across that interface, oxygen ions are transported and react with the hydrogen on the other side producing a flow of electricity and steam out the back of the fuel cell. In an aerospace plane, we could use this to manage total propellant flow.

This summarizes some of the benefits of hydrogen fueled aircraft. I have alluded to most of these so I won't read the chart, but it certainly gives one for transport aircraft the opportunity to fly at higher speeds with a nonpolluting vehicle at higher altitudes, much reducing the sonic boom overpressure effects of aircraft flying at hypersonic speeds.

The last technology I would like to address is that of advanced avionics. DARPA is engaged in broad-scale research programs and is pursuing advanced computers for many applications. In the aerospace plane area, we are particularly interested in some shown on this next chart where we no longer refer to vehicle or airplane flight control systems. Instead, we talk about vehicle management systems where the computer extends its tentacles throughout the air vehicle and, in particular, the active flight control of the vehicle and the active orbital control of the vehicle and the navigation and communications and control functions of the vehicle are all automated by these advancements in the avionics area.

If you will hold this last chart for me for just a moment, I will describe to you the program that DARPA envisions and then summarize.

DARPA plans to conduct a basic propulsion research and development program closely integrated with our compatriots at the NASA centers and indeed other U.S. centers of expertise which will lead to a program to construct and ground test large-scale proof of concept type engine modules. In addition to tests of large scale engines up to speeds on the ground of mach 8, tests of subscale engine components in special arc facilities where we don't have large enough facilities to test large scale, we go to smaller scale facilities, and both arc facilities and impulse facilities called shock tunnels can be used to verify our computational methods with supercomputer techniques and to provide detailed data on the fuel-air mixing heating rates, skin friction, and so on.

These test engines will fully replicate the conditions of an actual flight article. So, this we view as the key technology. In addition, our work in airturboramjets and a thing we call a cryojet which is a turbojet with a cooled inlet, can be developed and tested in the existing ground test facilities.

It is important to recognize that the facility testing is key here. While the full scale ramjet engines can be tested to mach 8 in the ground facilities, for higher speeds we are required to produce increased kinetic energy flows. We are then limited by the impulse facility and can literally only run for periods of milliseconds in these wind tunnels, thousandths of a second. Beyond that, we are fundamentally limited by our ground test facilities and must conduct exploration beyond mach 8 through flight test operation.

DARPA's hypersonic technology program will include the development and test of hypersonic engines, tests of critical engine parameters in high-speed facilities, impulse facilities, and application of these other technologies I have referred to. The focus of our effort is to envision an engine airframe integration which is configured by the use of the massive navier stokes computational codes which I showed you examples of earlier and the computational algorithms needed to calculate the viscous flow fields around the vehicle.

These activities are broad scale and national in nature. They are conducted with our friends at the NASA. They involve university research, and they involve aspects of American industry. We also intend to investigate the other technologies I have alluded to in my presentation.

The goal of this program will be to perform proof of principle tests on the critical technologies needed for hypersonic transatmospheric flight. It is estimated that several hundred million dollars over 2 to 3 years will be required to perform these critical proof of concept tests.

At that time, the technology development would be ready to proceed to a flight demonstration phase. Only through experimental flight tests and flight demonstration of the integration of these new technologies can confidence be developed to proceed with development of an operational system.

As with any program offering huge potential benefit and fully in keeping with DARPA's charter, there are technical costs and schedule risks. Technically, the performance of the air breathing propulsion system at very high speeds and altitudes, the strength and weight of the special high-temperature materials, the weight of the cryogenic tanks, these are principal risk areas that we foresee.

However, the good news is that for each of these, there are several technical options that can be developed in parallel. At this early stage of development, none of these risks appears to be unacceptable to us.

DARPA believes that the goal of efficient, affordable aerospace transportation vehicles can be attained and that the development and proof of concept tests of the critical technologies should begin now fully in concert with our friends at NASA.

If I may have the last viewgraph, DARPA, in summary, plans to undertake a new hypersonic technology program. The near-term goal of this program is proof of concept tests of a hypersonic propulsion system capable of very efficient operation from takeoff to orbital speeds. Enabling technologies such as advanced materials, actively cooled structures, lightweight tank concepts, and engine-airframe integration concepts needed to usher in a new generation of air breathing hypersonic, transatmospheric, aerospace—call it what you want—vehicles at the turn of the century will be pursued.

The technologies thus developed appear to offer the potential of substantially reduced cost per pound delivered to orbit for future space launch systems. For very high-speed transports, it could enable us to fly in 2 to 3 hours anyplace on Earth at acceptable direct operating costs, and, importantly, it is not just direct operating costs. It is the productivity, the product of payload times the speed which would enable an aircraft to operate perhaps not just one flight per day but two or three flights per day which would be the major economic lever in this process by going hypersonic.

We also believe this technology is, of course, highly applicable to military systems and that the many technology spinoffs of this U.S. technology focus will maintain our leadership in aeronautics and in the commercial use of space during the early decades of the next century.

Thank you, sir.

Mr. BROWN. Thank you.

Dr. BUFFALANO. Mr. Chairman, before we close our testimony and take questions, I would like to ask Dr. Robert Cooper for his observations on this opportunity.

Dr. COOPER. Thank you, Mr. Chairman.

I think that the program that ARPA has started here represents a really unprecedented opportunity for the country. I believe I share that view with a number of the other witnesses today.

However, I would like to point out again that both the technologies that have been matured over the last 10 or 15 years and the need for aircraft that may be enabled by these technologies seem to be coming together at the same time. As you well know in this committee, the space shuttle, by the end of this century, will be obsolete or obsolescent.

The design criteria by which the shuttle was developed were such that the design was only to last for a number of orbital missions, about 100, and we can expect that those orbital vehicles will begin to wear out along with the engines and other parts that are in the system today. Unless we procure new orbiters, new systems of exactly the same kind, we will be looking toward a followon to the space shuttle at some time in the 1990's decade when the development will have to take place in order for the new systems to be ready for space launch by the end of the century.

This technology, I would guess, will represent a major potential player in that game for the new system.

In civil aviation, our desire to reach further to nations with greater economic power that are further from our shores is great, as others have testified. That need is apparent even today. Having systems that can reach those nations in 1 or 2 hours as opposed to 10 to 20 hours is going to be important, I believe, not only for the Pacific but also for the Atlantic and other areas in the globe.

Nowhere is the technology going to be more important than in its military applications, in my judgment, and that is why DARPA was involved in that. Even though I am no longer with DARPA, I was instrumental in steering DARPA's activity in this area and it was because of my firm belief that the threat from the Soviet Union is great and that the need to have truly global reach for our interceptor systems and for our aircraft interdiction systems in the next decade. The need will be so great that this technology will be the only means by which we can substantially meet our military needs in this area.

A couple of other points I would like to make. It may appear from our description here of the ARPA Program that ARPA is really responsible for this technology, but I would like to point out that after the major emphasis was relaxed on hypersonic flight in the 1960's time period, NASA in its relentless way continued to develop the technologies of supersonic combustion ramjets and the other technologies that are needed to make vehicles of this sort happen.

They have done that at a very low level, taking it out of their discretionary funding in their research programs, and they have done it with little recognition. I would like to say that they deserve the support of this committee in their broad role in the new DARPA Program for increased levels of funding and activity. I be-

lieve that this committee could serve the Nation's interest well by supporting NASA's upcoming requests for new funds in this area, and I would commend that to you.

Let me just close by saying that the level of activity in ARPA today was set over a year ago by overall ARPA budget considerations. As a matter of fact, I personally was very skeptical that this technology could be brought together in the way that Bob Williams has described to you today. In challenging him to prove it, I was one of the most surprised of the people who have reviewed this technology area over the past year to learn that all of my questions were suitably answered.

After Bob has put together a team of about 40 or 50 of the finest researchers in the United States to answer the questions that I asked at that time, and after the 3 days' intensive review that I did of that program in San Diego some months ago, I am thoroughly convinced that now is the time. The Nation can, if it chooses, make heavy new investments in this area which will pay off in the 1990's with exciting new capabilities for space, for civil aviation, and for military aircraft and aerospace planes.

Thank you very much. I would be happy to join with these folks in answering any questions you have about this technology or our programs.

[The prepared statement of Dr. Buffalano follows:]

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

HYPERSONICS TECHNOLOGY PROGRAM

Statement to The Subcommittee on

Transportation Aviation and Materials
of
The Committee on Science and Technology

United States House of Representatives

July 24, 1985

Dr. Charles Buffalano

DARPA'S HYPERSONICS TECHNOLOGY PROGRAM

INTRODUCTION

The Defense Advanced Research Projects Agency is currently developing technologies in airbreathing propulsion, strong, lightweight, high-temperature materials, cryogenic fuel tanks, efficient hydrogen utilization systems, and advanced "intelligent" avionics for new classes of hypersonic aircraft that would be potentially capable of flying to any point on earth within an hour of takeoff or acceleration to orbit after takeoff from a normal airport runway. The goal is to provide technology for a liquid-hydrogen or methane fueled, airbreathing, ramjet/scramjet propelled vehicle capable of operation at extreme hypersonic speeds. This technology could allow a horizontal takeoff aircraft to cruise in the atmosphere at Mach number of 6 to 12 at altitudes over 100,000 feet. Alternatively it could permit a horizontal-takeoff-and-land single-stage-to-orbit vehicle.

A ramjet, as its name implies, uses the ram air pressure resulting from the forward motion of the vehicle to provide jet engine compression. It has neither the compressor nor the turbine of a turbojet engine, and it normally cannot produce thrust at low velocity since speeds of several hundred miles per hour are needed to provide the ram air compression. The ramjet inlet slows down the incoming air while compressing it, then burns the fuel and air subsonically and exhausts the combustion products through a nozzle to produce thrust. At speeds above Mach 6 the high temperatures associated with slowing the air to subsonic speeds results in a loss of engine performance. To fly faster the internal geometry must be varied in order to allow the air to remain at supersonic speeds through the combustor. This is called a supersonic combustion ramjet or scramjet and potentially has speed capability to Mach 12 or more.

In addition to the hydrogen fueled ramjets, DARPA is also developing propulsion technology for combined cycle engines called ' Airturboramjets' and 'Cryojets.' These engines could utilize a variety of fuels including solid rocket type fuels, liquid hydrocarbon fuels, and methane or hydrogen fuels. The Airturboramjet has a compressor similar to todays turbojets, but the air that goes through the compressor does not pass through the turbine which drives the compressor. Instead the turbine is driven by a gas generator and air from the compressor mixes with the fuel rich gas exhausting from the turbine and burns in a ramjet type combustion chamber. Because the turbine is driven by a gas flow independent of the air entering the inlet and compressor, and the fact that the primary combustion takes place downstream of the turbine, the turbine temperature is independent of the flight Mach number. With high temperature materials in the compressor, speeds of Mach 5 or slightly higher are possible with high efficiencies and high thrust to weight ratio. DARPA plans to undertake a "proof-of-concept" type demonstration of airturboramjet technology in which a small scale engine will be designed, fabricated, and tested at conditions simulating flight between speeds of zero and Mach 5. The 'Cryojet' is a concept which cools the incoming air to the compressor stage.

Both the airturboramjet cryojet and the ramjet/scramjet engine represent credible propulsion options for a hypersonic hypersonic aircraft using either hydrogen or methane fuel. The materials, tanks and avionics technologies

mentioned above which are being developed for military applications are also directly applicable to the high speed transportation systems of interest to this committee.

BACKGROUND

In the 1960's the Air Force, the Navy and NASA invested heavily in research and development on hydrogen fueled scramjet engines. Both the Air Force and Navy terminated their hydrogen fueled scramjet research when NASA's Mercury, Gemini and Apollo programs selected and developed hydrogen-oxygen rockets for space launch. Rockets were the first propulsive means used in supersonic and hypersonic flight. Both the X-1 research aircraft (first plane to break the sound barrier) and the X-15 research aircraft (first plane to fly at hypersonic speeds) were powered by rocket engines. The physics of rocket operation was well understood. Furthermore, rocket technology was more mature; ICBM's and air-to-air missiles used rockets. While subsonic combustion ramjet technology was fairly well understood and some ramjets were in use in operational missiles (BOMARC and TALOS), the understanding of supersonic combustion phenomena was in its infancy at the beginning of the space age. In addition, rockets could be completely developed and tested on the ground and their performance accurately determined for operation at any speed in the atmosphere or space. Therefore, rockets were naturally the first engines to be used in the race for space.

WHAT IS NEW?

While most research in scramjet technology was terminated in the 1960's, NASA, at its Langley Research Center, continued to sponsor a low-level, in-house research program in hydrogen fueled scramjet engines and have actually built and tested several sub-scale engines. One of the scramjet engines tested by NASA had a flight weight regeneratively-fuel-cooled structure which demonstrated the possibility of a relatively long life and very low weight propulsion system. Over the last 5 years NASA Langley has conducted more than 1,000 tests of subscale, hydrogen fueled, fixed geometry scramjet engines at simulated flight conditions of Mach 4 and Mach 7 and measured performance levels sufficient for acceleration of a large aircraft.

What has made it possible for us now to reexamine the issue of ramjet propulsion are many recent advances in relevant enabling technologies. Among these are advanced computational tools, high temperature lightweight materials, actively cooled structures, lightweight cryogenic tank concepts, hypersonic aerodynamics (with special attention to engine-airframe integration), efficient hydrogen utilization systems and advanced "intelligent" avionics. Progress in these areas when combined with recent advances in ramjet/scramjet propulsion justify serious consideration of new modes of transportation into hypersonic and transatmospheric flight.

In the first area, new, efficient, 2-dimensional and 3-dimensional computational fluid dynamics methods and the advent of advanced super computers now make it possible to calculate the complex flow within a hydrogen burning supersonic combustor and determine its performance. Previously only simple one-dimensional engine cycle analysis methods could be used because of computational limitations, even though they were wholly inadequate to model a scramjet engine.

In the materials area, DARPA is addressing broad based research in metallic, composite, and ceramic materials capable of very high temperature operation and high strength-to-weight ratios while retaining the basic property of reusability and long life. These latter features held the key to low maintenance and operation costs. Promising approaches to high temperature materials currently include Rapid Solidification Rate (RSR) metals, carbon-carbon composites and silica based ceramics. RSR materials are metals wherein the microstructure and properties are "frozen" with ultra-rapid, quenching of tiny particles. Third generation advanced Carbon-Carbon materials are capable of withstanding temperatures even higher than the temperatures experienced during re-entry by the current carbon-carbon structures used on the nose and leading edges of the Space Shuttle. These new material technologies clearly are useful in many applications other than aerospace.

Hydrogen, as a fuel, has some very unique properties. It holds the promise of achieving independence from foreign petroleum resources. It can be made easily from steam reformation of natural gas (CH_4) or it can be made from water and any other energy source such as fossil, nuclear, solar, or biomass. Hydrogen combustion is non-polluting because its combustion product is water, and water does not endanger the ozone layer. Contrary to misconceptions surrounding the Hindenburg disaster, hydrogen is actually a safer fuel than gasoline in that it burns with a non-propagating flame. Hydrogen rapidly dissipates in the atmosphere due to its extremely light weight which means that it does not tend to collect or form a concentrated cloud that could be ignited explosively. Hydrogen also offers some advantages to aircraft operation. Hydrogen aircraft would have a lower gross weight, because of the low specific gravity of its liquid state, and thus perhaps a lower cost. Finally, as fossil fuel supplies become outdistanced by demand, hydrogen may be expected to eventually become less expensive than petroleum fuels.

DARPA is exploring some of the key technologies needed for widespread use of hydrogen as a fuel. These include: efficient production, long term cryogenic storage, and direct conversion of hydrogen into electricity. One exciting new technology is an energy conversion device called a "Monolithic Solid Oxide Fuel Cell." This device, which is under development for DARPA at the Argonne National Laboratory, may have a very dramatic impact on our energy future. Resembling a bee-hive and employing microminiaturization of ceramic materials having doped electronic properties the fuel cell can generate unprecedented levels of power to weight ratio and efficiency. It offers a tremendous potential as an energy source for many future vehicles and for use in space. It also has the useful property of being able to operate in reverse, so that in conjunction with solar cells or some other form of electric power, water can be converted directly into hydrogen and oxygen.

The primary emphasis of DARPA's Hypersonic Technology Program is the development of the ramjet/scramjet propulsion capable of operation, up to very high speeds. There are a number of interesting and highly challenging technical barriers associated with such a propulsion system, but none of them appears insurmountable. The technology being explored by DARPA would enable the propulsion engines to cover three different flight regimes: take-off, hypersonic, and [illegible]. Such a system of propulsion engines would have to be carefully integrated with the airframe. Proper integration of the airbreathing inlets into an aircraft is a critical design problem since the

shape of the airframe itself determines, in large part, the performance of the engine. For example, in scramjet operation the forward vehicle underbody would account for a large part of the inlet compression and the vehicle afterbody shape would form the nozzle and produce half of the thrust at high speeds.

The potential performance of such an engine is best described by a parameter known as the average specific impulse (I_{sp}) which is a measure of the pounds of thrust from the engine per pound of fuel flow through it each second. This measure has as its units seconds and the larger it is the more efficient the propulsion. Over the speed range of Mach 0 to 25, the various engines could have an average I_{sp} in excess of 1200 seconds. This compares with an I_{sp} of only 470 seconds for the best hydrogen-oxygen rocket engines such as the Space Shuttle Main Engines. It is the much higher I_{sp} of an airbreathing engine capable of operating from take-off to orbit that will make possible a single stage, horizontal-take-off-and-land aero space plane. At 'lower' speeds for airplane-like cruise (Mach 6-12 over 100,000 feet) the average I_{sp} is even larger making the scramjet attractive for an earth-to-earth transportation system. The fact that the propulsion system is comprised of several similar or perhaps identical modules makes it possible to develop and test full size engines in ground test facilities from simulated flight speeds of zero to Mach 8.

In the area of the Airturboramjet and Cryojets, it is the new materials developed over the past ten years that make possible operation above the previous limit of about Mach 3-4. Now, however, using a compressor similar to today's commercial jet engine turbines, the ATR should be able to operate at higher speeds and have a much higher thrust-to-weight ratio than present turbojet engines.

PROGRAM ENVISIONED

DARPA plans to conduct a basic propulsion research and development program closely integrated with NASA and other centers of expertise which will lead to a program to construct and ground test large scale, "proof-of-principle," hydrogen fueled engine modules. In addition to tests of large scale engines up to speeds of Mach 8, tests of subscale engine components in arc facilities and impulse facilities such as shock tunnels will be used to verify computational methods and provide data on fuel-air mixing rates, wall skin friction and heating rates, and other engine performance parameters. The test engines will have full scale combustors, and in fact all of the engine internal flow geometry, is planned to be full scale. However, that portion of the inlet and nozzle which is external to the engine duct and therefore part of the airframe itself can only be partially simulated in ground tests.

Airturboramjets and cryojets can be developed and tested on the ground in high speed wind tunnels in full size to Mach 4 or even higher although the absence of extensive aerodynamic integration with the airframe and the lower kinetic energy levels of the lower Mach number flow limit the applicability of the results somewhat. The rocket portion, of course, operates independently of the surrounding airstream except for a slight dependence on the ambient pressure into which it exhausts. It can be completely developed and tested on the ground and its performance accurately determined for operation at any speed in the atmosphere or space.

While full scale ramjet engines can be tested to Mach 8 in ground facilities, for higher speeds shock tunnels are required to provide the high kinetic energy flows. These facilities run for extremely short periods of time and thus, only limited simulations can be obtained. These facilities are suitable for sub-scale tests such as fuel injection, fuel-air mixing, and combustion. Such data are valuable for verifying theories and calculations. Despite the utility of shock tunnels above Mach 8 ground test facilities cannot be used to fully verify scramjet engine performance so that eventually, flight research and demonstration is required.

Thus, there are two fundamental limitations to ground test of any hypersonic, airbreathing engine. One is the very high degree of aerodynamic integration of the engine and airframe which would require test of the complete vehicle to provide full simulation and which would present prohibitively costly facilities. The other is the necessity to duplicate the kinetic energy of the flight airstream entering the engine to duplicate properly the supersonic combustion process. Mach 8 is about the practical limit for ground facilities capable of duplicating flight kinetic energy at full scale with run times sufficient for turbo, cryo or scramjet type engines.

DARPA's Hypersonic Technology Program will include the development and test of hypersonic engines, tests of critical engine parameters in high speed impulse type facilities and the application of new computational methods and larger supercomputers to calculate the complex internal engine flow and engine performance. The focus of DARPA's engine-airframe integration is principally the application of massive "Navier Stokes" computational algorithms which when programmed on the most advanced supercomputers can calculate the viscous flow fields around the vehicle and inside the engine itself. These activities are joint undertakings with NASA.

In addition to the development of the propulsion technology DARPA is also planning to investigate other technologies such as advanced materials, actively cooled structures, lightweight tank concepts, hypersonic aerodynamics (with special attention to engine-airframe integration), efficient hydrogen utilization systems, and advanced 'intelligent' avionics. The goal of this program will be to perform "proof-of-principle" tests of the critical technologies needed for hypersonic and transatmospheric flight. It is estimated that several hundred million dollars over two to three years will be required to perform these critical "proof-of-concept" tests. At that time the technology development would be ready to proceed to a flight demonstration phase. Only through flight tests and flight demonstration of the integration of these new technologies can confidence be developed to proceed with development of an operational system.

As with any program offering huge potential benefit there are technical, cost and schedule risks. Technically, the performance of the air-breathing propulsion system at very high speeds and altitudes, the strength and weight of the special high temperature materials, and the weight of the cryogenic tank concept are the principal risk areas. However, for each of these there are several technical options that can be developed in parallel. At this early stage of development, however, none of these risks appears unacceptable, and DARPA believes that the goal of efficient, affordable aero space transportation vehicles can be obtained and that the development and "proof-of-concept" tests of the critical technologies should begin now.

SUMMARY

DARPA plans to undertake a new Hypersonic Technology Program. The near term goal of this program is "proof-of-concept" tests of a hypersonic propulsion system capable of very efficient operation from take-off to orbital speeds. Enabling technologies such as advanced materials, actively cooled structures, lightweight tank concepts, and engine/airframe integration concepts needed to usher in a new generation of airbreathing hypersonic transatmospheric vehicles at the turn of the century will also be pursued. The technologies thus developed appear to offer the potential of substantially reduced costs per pound delivered to orbit for future space launch system, very high speed transports that will allow 2 to 3 hour flight times from the United States to the Orient at acceptable direct operating costs and highly effective military systems. These and many spin-off applications of this technology will maintain US leadership in aeronautics and in the commercial use of space during the early decades of the next century.

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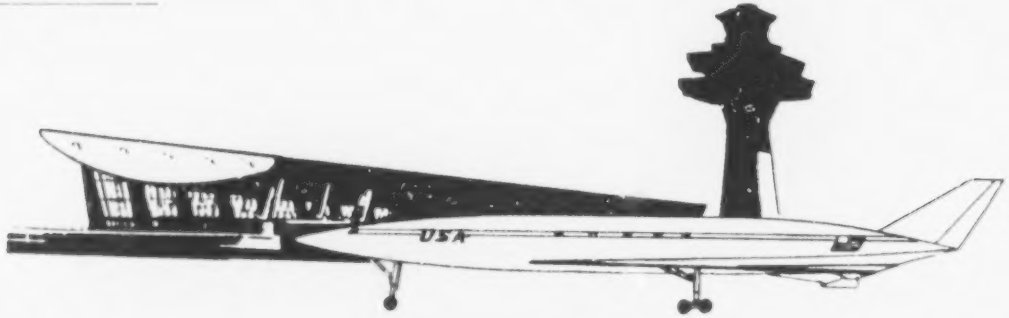

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LOS ANGELES-TOKYO
2 HOURS

CIVIL

WASHINGTON-LONDON SHUTTLE
1.5 HOURS

4566/85W/GW25/1A

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(U) AND A SPACE PLANE....

WITH PAYLOAD-TO-ORBIT COSTS OF 1/100 OF TODAY'S COSTS

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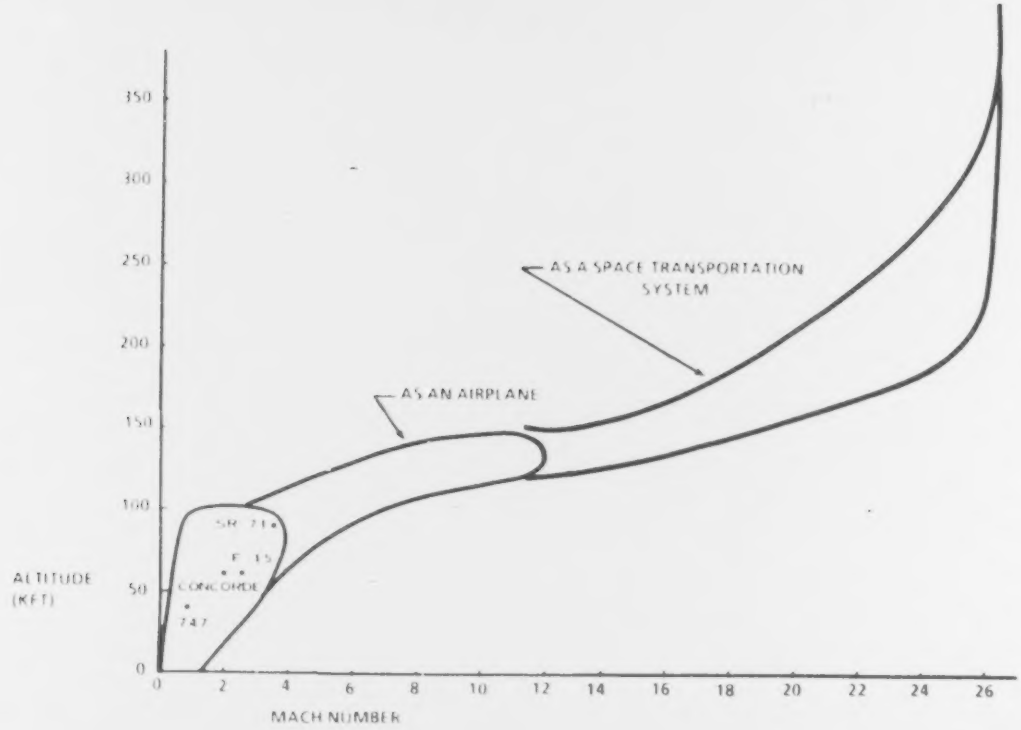
51-341 O—85——3

(U) ATMOSPHERIC FLIGHT ENVELOPES



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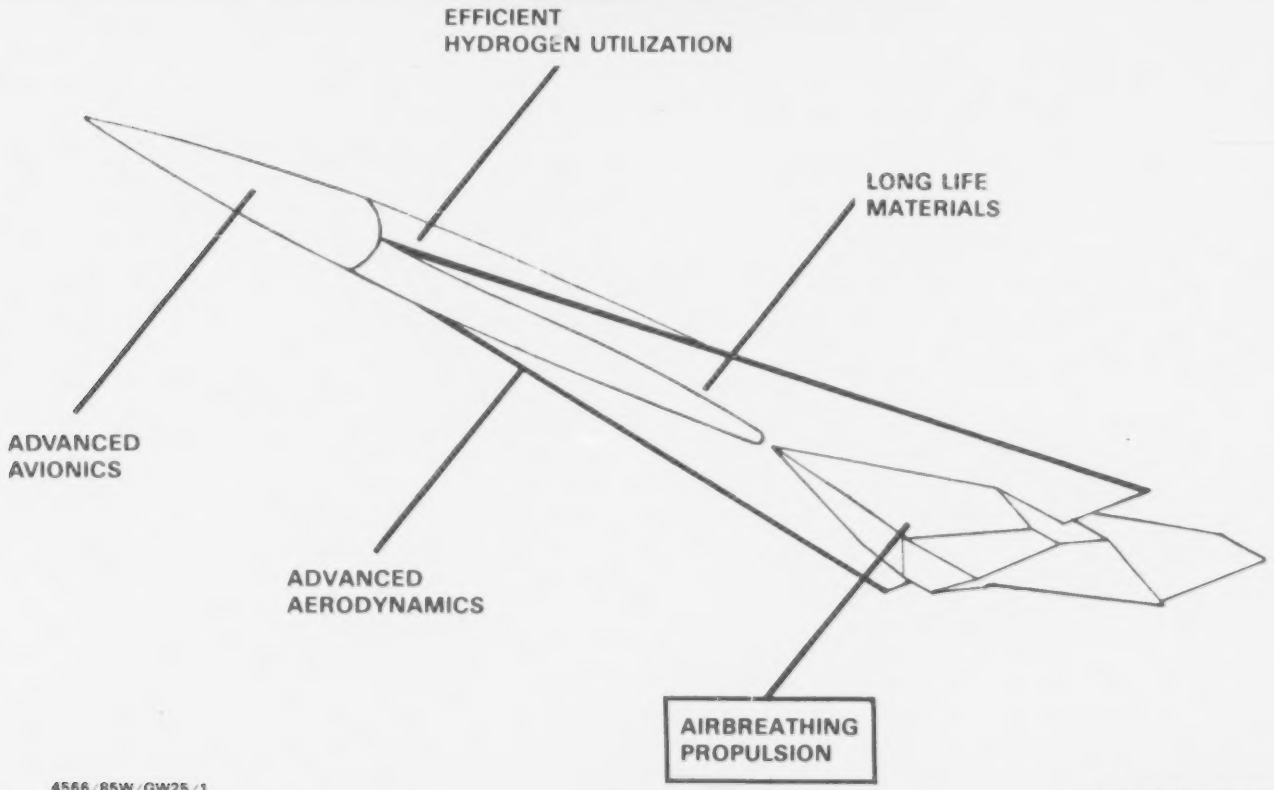
(U) KEY AERO-SPACE PLANE TECHNOLOGIES



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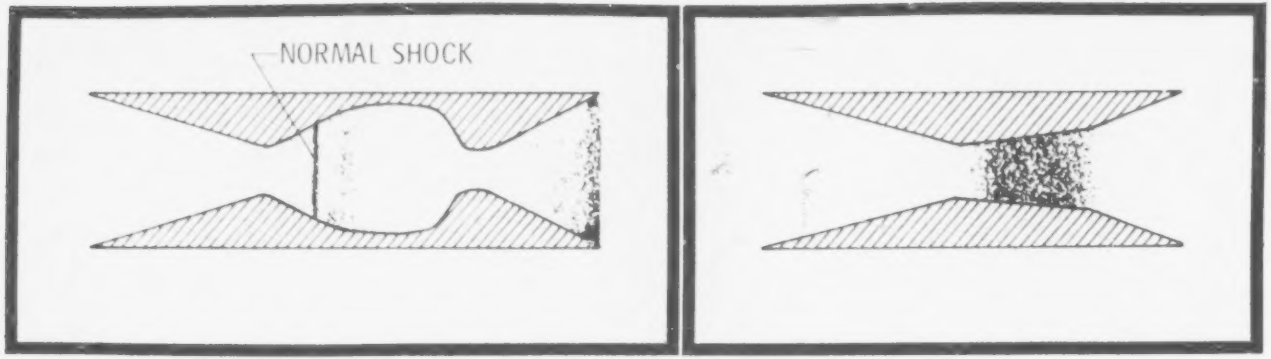
(U) HIGH SPEED ENGINES

RAMJET

MACH 2 TO 4

SCRAMJET

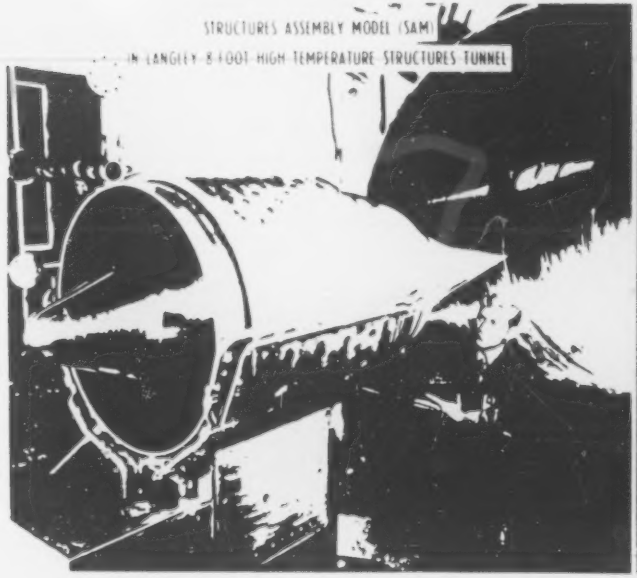
MACH 4 TO ?



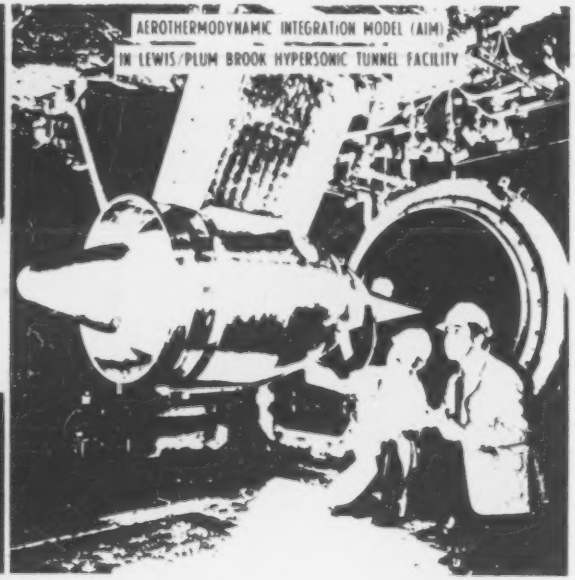
SUBSONIC COMBUSTION

SUPERSONIC COMBUSTION

(U) NASA HYPERSONIC RESEARCH ENGINE PROJECT

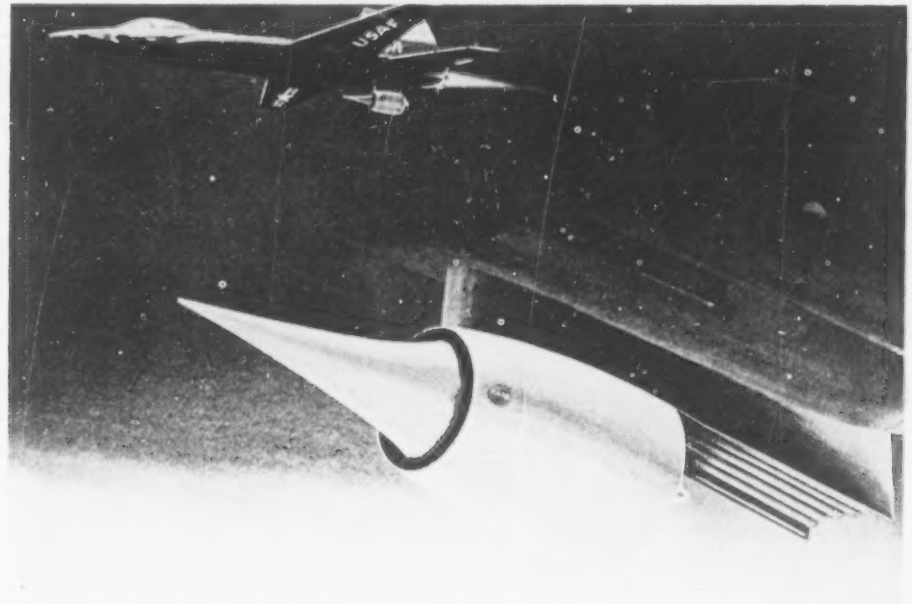


STRUCTURES ASSEMBLY MODEL (SAM)
IN LANGLEY 8-FOOT HIGH TEMPERATURE STRUCTURES TUNNEL

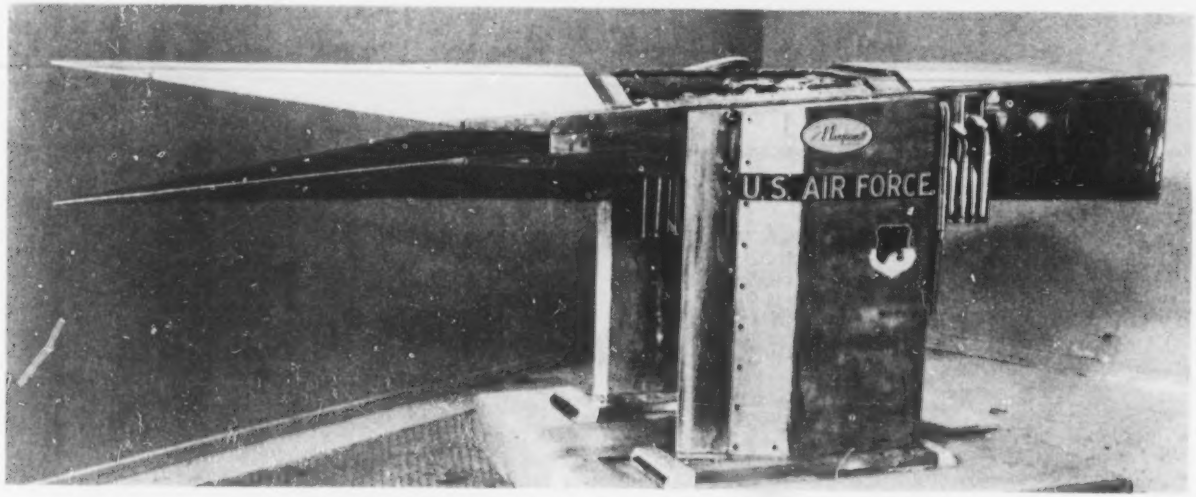


AEROTHERMODYNAMIC INTEGRATION MODEL (AIM)
IN LEWIS/PLUM BROOK HYPERSONIC TUNNEL FACILITY

(U) HYPERSONIC RESEARCH ENGINE DESIGNED FOR X-15



(U) AIR FORCE DUAL MODE SCRAMJET



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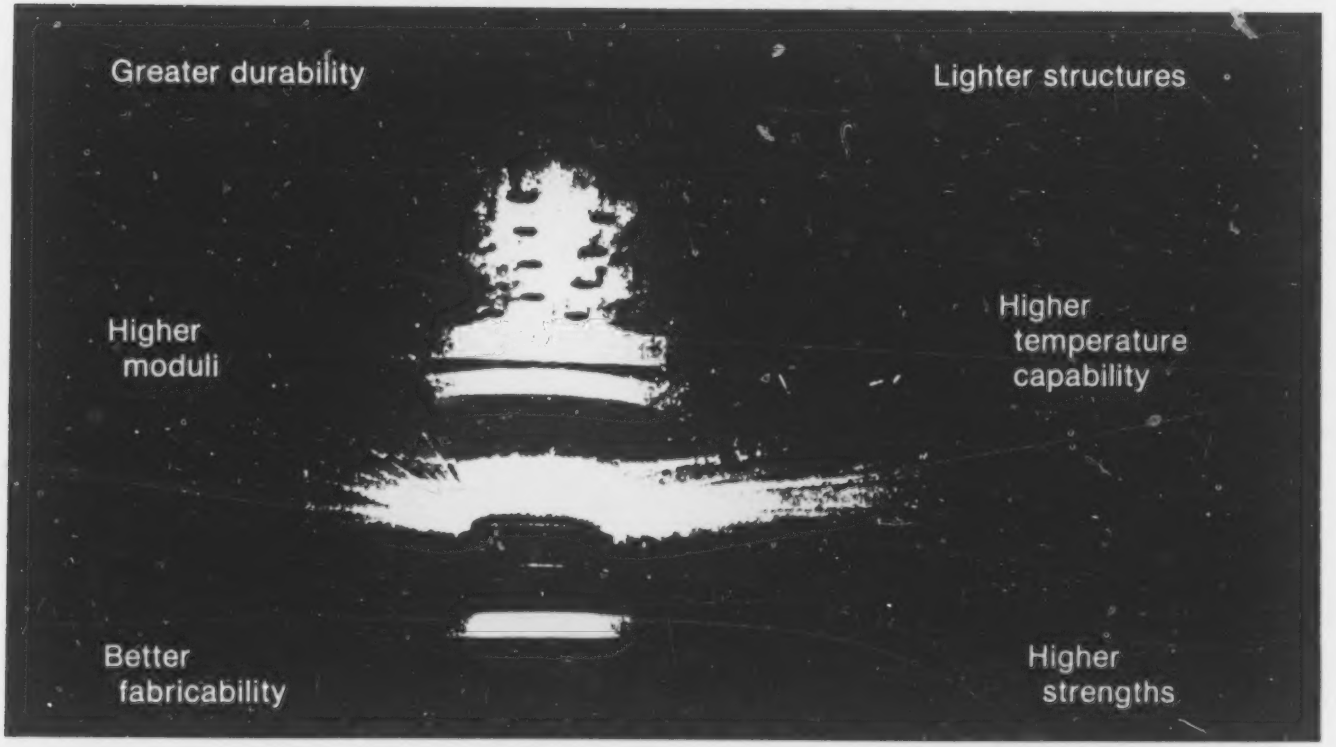
(U) RAPID SOLIDIFICATION RATE (RSR)



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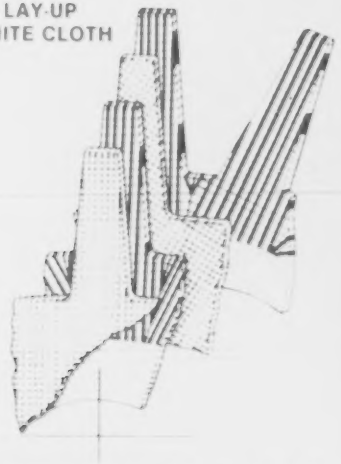
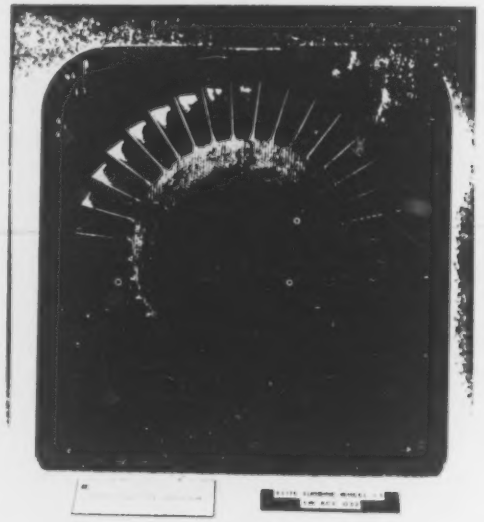
(U) ELITE CARBON/CARBON TURBINE ROTOR SUSTAINS TEST SPEED OF 40,000 RPM

TAILORED LAY-UP
OF GRAPHITE CLOTH





OUTSIDE DIAMETER = 14.47 IN.
NO. OF BLADES = 36
WEIGHT = 7.5 LB
DESIGN SPEED = 34,640 RPM

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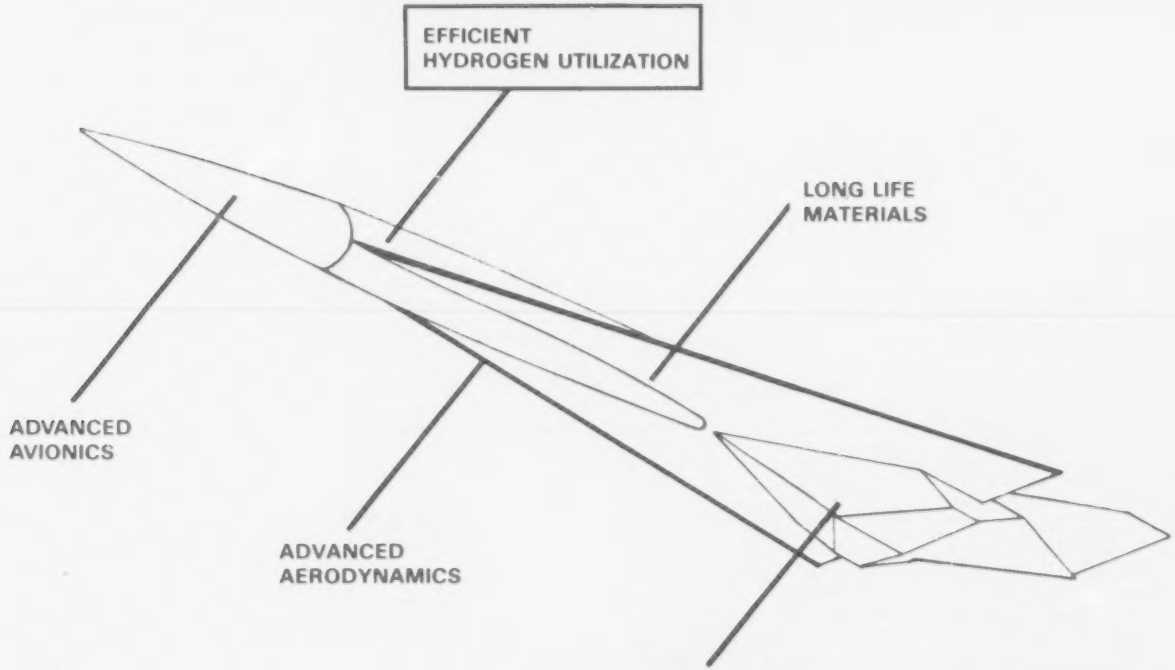
(U) KEY AERO-SPACE PLANE TECHNOLOGIES



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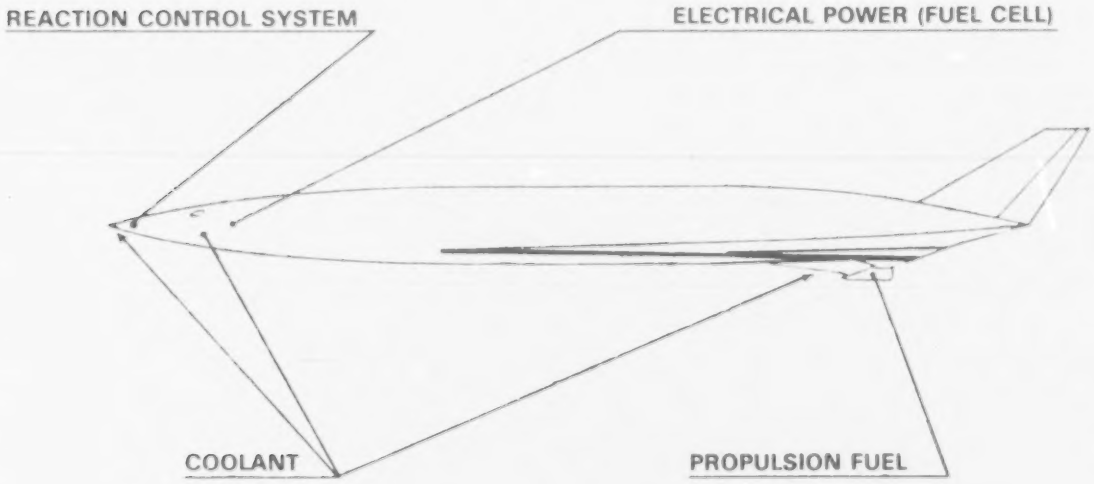
(U) EFFICIENT HYDROGEN UTILIZATION

- LIQUID HYDROGEN HAS MAXIMUM ENERGY PER POUND
- USED AS A FUEL AND AS A COOLANT



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(U) BENEFITS OF HYDROGEN-FUELED AIRCRAFT

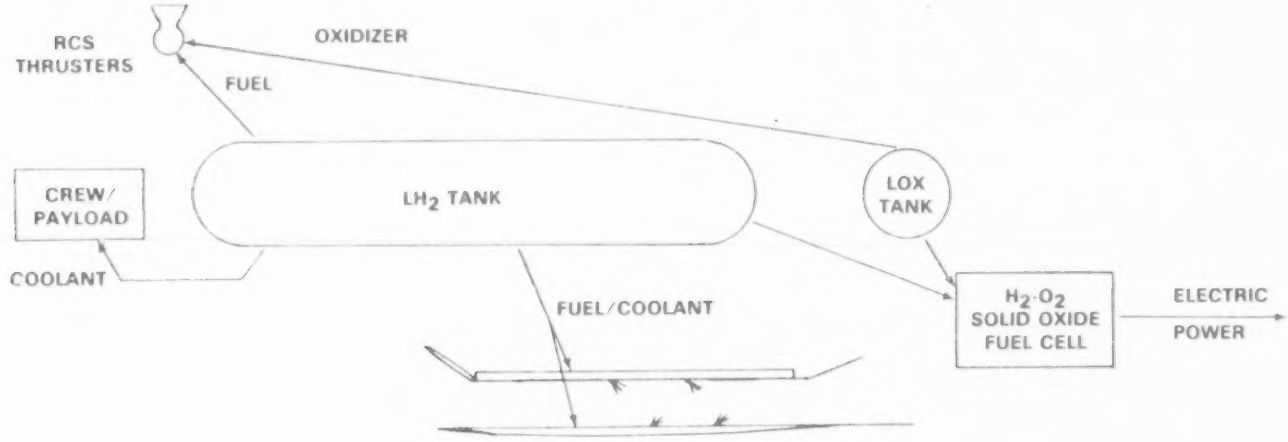
ADVANTAGES OF HYDROGEN FUEL

- INDEPENDENCE FROM FOREIGN RESOURCES
- CAN BE MADE FROM NATURAL GAS (CH_4)
- CAN BE MADE FROM WATER AND ENERGY SOURCE
  - COAL, NATURAL GAS, NUCLEAR
  - DIRECT SOLAR
  - BIOMASS
- NON-POLLUTING COMBUSTION (PRODUCES WATER)
  - HYDROGEN BURNING DOES NOT ENDANGER OZONE LAYER
- HYDROGEN IS SAFE
  - NON-RADIATING FLAME, RAPID DISSIPATION, NON-TOXIC PRODUCTS
  - TESTS SHOW SAFER THAN CONVENTIONAL FUELS (BUT FACED WITH HINDENBERG STIGMA)

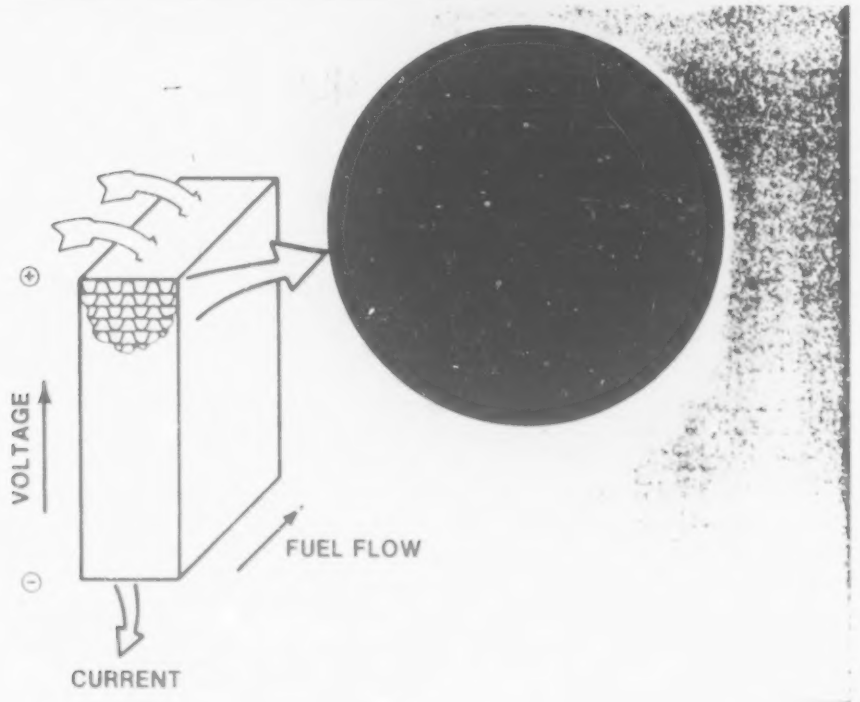
ADVANTAGES OF HYDROGEN FUEL TO AIRCRAFT OPERATION

- LOWER GROSS WEIGHT/LOWER COST AIRCRAFT
- IMPROVED ENGINE OPERATION
  - COOLED COMPONENTS, ELIMINATE CARBON FOULING
- HYDROGEN EVENTUALLY CHEAPER THAN PETROLEUM FUELS

(U) EFFICIENT HYDROGEN MANAGEMENT: A KEY TO LARGER PAYLOADS



(U) MONOLITHIC FUEL CELL



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Mr. BROWN. Thank you. That is an excellent presentation. Are you ready for questions now?

Dr. BUFFALANO. Yes, sir.

Mr. BROWN. All right. Would you care to ask any questions Mr. Lewis?

Mr. LEWIS. Mr. Chairman, I have a couple of questions, I guess for Mr. Williams.

When do you feel the flight test program will be ready with a transatmospheric vehicle that you have envisioned?

Mr. WILLIAMS. Mr. Lewis, we are engaged in an activity to try to prove that propulsion technology first. That is the tall pole in our technological tent. That would take on the order of 2 to 3 years and on the order of $300 to $400 million of DARPA/DOD-type support in addition to active support from NASA just to get that far.

Once we get to that critical milestone, the time period to get to a flight vehicle would literally be determined by the funding available to us. It could be as little as 2 or 3 years once we have matured those technologies.

Mr. LEWIS. So, you are talking at the earliest probably 7 years.

Mr. WILLIAMS. Something on that order, perhaps less.

Mr. LEWIS. Have you looked at the deterioration of the space shuttle program and where this is a follow-on as was mentioned earlier, and have you looked at a timetable and timeframe to follow on the space vehicles? You are concerned about the funding for the flight vehicle. What is your best scenario and worst scenario?

Dr. COOPER. Perhaps I could field that question. This was one of the considerations that we discussed in some detail last year. It was our judgment that around the turn of the century is the need date for a new space transportation system of some sort. There is a joint NASA/Defense committee that is studying follow-on space transportation systems now. That study was mandated by a Presidential directive a short while back, and I would suspect that by the end of the year, its findings will be out.

However, clearly, we have timed the program activity in this area so that the readiness of the technology in the 1990s would be there for a decision to employ this technology as opposed to rocket technology if that were the technology of choice. So, I would view a 7-year program which would end in about 1992 or 1993, if adequately funded, with a flight demonstration of this capability and a full maturation of the technologies involved and with the ability then to start a program in the 1993-1994 time period that would end up with a new space transportation system by the year 2000 with maybe a 7- or 8-year development time for that system.

Mr. LEWIS. Do you envision—let me ask it differently. Do we have the type of facilities for component testing at this point in time or how long would it take to develop these facilities to meet the criteria prior to your envisioned flight time?

Dr. COOPER. The current view is that the facilities that are available plus those that can be upgraded in the next few years will be adequate to test the engine concepts that we will be testing in the near term up to about mach 8. Beyond that, as Bob pointed out, you will need flight tests, and it would be mainly for that reason, that is, to test the propulsion in the mach number ranges from 8 to

25 that such a flight test program would be mounted, in my judgment.

Bob, do you have anything to add to that?

Mr. WILLIAMS. Yes, sir. I would just like to make it clear for the record that what DARPA is contemplating here, and only contemplating, is some sort of a technology demonstration vehicle initially that would, if you will, mature the technologies through development sufficient to make a decision to go ahead with a larger scale vehicle later either an endoatmospheric transport or a space transport type system.

Mr. LEWIS. I see. Would the program that you envision at this point provide the applicable results for both the civil transport mission as well as a single stage to orbit transatmospheric vehicle?

Mr. WILLIAMS. To a very large extent, it would. There are some differences which we need to look at in great detail that are unique to the civil and unique to the military on the other hand, but I think in close cooperation with our friends at NASA we could fully address those areas by the time we completed the technology demonstrator program.

Mr. LEWIS. I see. Maybe Dr. Cooper can answer this one. Do you envision a flight vehicle at slower speeds, say, at mach 5 and work up, or would you be looking at a vehicle that would fly at mach 5 or 7 and then use rocket boost to go into orbit, or would you be putting all your eggs in one basket initially to go with a single power plant to go from air flight to space flight?

Dr. COOPER. I think the planning for flight test program and just exactly what kind of a vehicle to flight test is still ahead of us. It is not clear yet whether one should in essence shoot for the moon and go for the most stressing mission which would be the mission to orbit or whether suitable flight testing could be done at mach numbers, say, below 10, or maybe it would take a combination of the two. It is not clear yet what the situation will be. I think we will know much more about that in about 2 years after we see how the ground testing of the engine, how the engine research and development activities are going, just exactly what kind of a flight test program to structure.

Mr. LEWIS. Do you have built into your program for both your demonstrator plus your flight test the expedient development for higher computer technology in order to meet the requirements for the high mach number flying and the into orbit flights?

Dr. COOPER. Congressman, we have a separate program at DARPA that we are pursuing in new generation computers. Basically, we have a program which was started about two years ago and which will soon be moving into its third year of effort, a program that has been running at the level of about $100 million a year and will move up to about $150 million in fiscal year 1986 to develop an entire new generation of multiprocessor computers and artificial intelligence software systems that can operate on these computers.

It is my view that this new generation of computers will be all that will be required in the new avionics capabilities of these hypersonic vehicles. They have the other very important property that they are totally fault tolerant, that is, the processors themselves may range in numbers from several hundred upwards

toward a million processors in one single computer. Consequently, the computers can be programmed and designed and embedded in a control system in such a way that there is virtually no chance of failure of those machines.

We believe that the expenditures that we are making in the strategic computing program which is this DARPA Program I described to you will provide all of the capability needed for these new hypersonic vehicles. It is a very nice marriage of two technologies which are being developed essentially independently.

Mr. LEWIS. I see. Thank you, gentlemen. That is a fine presentation.

Thank you, Mr. Chairman.

Mr. BROWN. Mr. Nelson.

Mr. NELSON. Thank you, Mr. Chairman.

How did you start to focus in on this particular propulsion concept?

Mr. WILLIAMS. One of the charters that DARPA has and one of the reasons it is the best place in the U.S. Government to work today is that we are asked to look at the boundaries of our technology, to understand what the technological limits are. Our endeavor was to determine what are the upper limits to speeds for air breathing engines. Previously we had flown air breathing really only up to about mach 4. There was one particular ramjet that flew up to mach 5, but we pursued how far could you go.

Over the period of several years, we concluded that we really don't know how fast you can go air breathing, but it looks very, very fast, and that is really what led us to the scramjet type propulsion technology.

Mr. NELSON. As you looked at that—now, are you using interchangeably the word scramjet with air turbo-ramjet?

Mr. WILLIAMS. No, Mr. Nelson. An air turbo-ramjet is a turbine-type propulsion system which could operate up to speeds on the order of mach numbers of 5 or so and then would require a switch over to the scramjet mode in order to enable it to go faster.

Mr. NELSON. I see. Now, you mentioned the early technologies since the mid-1960's. What is new in this technology since that research that Scott was testing out there at Edwards? That hypersonic engine that they were testing was cancelled, so what is new in the technology that gets you to where you are now?

Mr. WILLIAMS. What is new is principally that a lot more work has been done. NASA Langley, for example, has conducted over 1,000 scramjet engine tests since that period when Scott was flying. What else is new is that the materials technology to be able to build that engine so it won't burn up has recently come about. Perhaps most importantly of all, the supercomputers have landed upon us, and just within the last few years, we have been able to calculate and compute the flow fields over these bodies. We did not have these technologies before.

Mr. NELSON. With the SST, the sonic boom is a problem. Why don't you share with us why the sonic boom is not a problem with this?

Mr. WILLIAMS. That is a difficult question to deal with. The sonic boom is both a technical and a public acceptance problem. Let me just describe that briefly to you.

A typical supersonic transport would produce a slight overpressure at the Earth's surface. That is, the shock wave created by the fact that the aircraft is flying faster than the speed of sound produces an impulsive pressure rise. That pressure rise propagates to the ground and is felt as a very sharp rise in pressure.

Now, it turns out that the magnitude of the pressure rise is very small. The sea level air pressure is about 2,100 pounds per square foot, and a supersonic transport would only have an overpressure of 2 to 3 pounds per square foot more, so it doesn't sound like it is really very much at all. However, unfortunately, the human ear is extremely sensitive to impulsive sounds. The human ear, certain human ears, young ones can perhaps measure overpressures down to values as low as one-tenth of 1 pound per square foot.

Now, for an aerospace plane to ever completely eliminate that is very, very difficult, but you do have an environmental factor going for you, and that is simply the fact that you are cruising at such an altitude and such a speed that the overpressures we anticipate at the ground are on the order of five-tenths, one-half of 1 pound per square foot, so about six times lower than what was talked about for the supersonic transport.

Now, is this viable for overland transportation? Sir, I couldn't tell you. It would depend on the public acceptance of a kind of a thump in the distance. I myself lived in Southhampton, England, for a period of time, and I used to hear the Concorde as it cruised to supersonic. We actually got a thump-thump, because it bounced off the atmosphere and you got two sounds coming back. I never had any problem at all with that. In fact, you had to listen very carefully for it.

So, perhaps it will be like the people living near the train station. After a while, the public acceptance will come in, but I think it would be necessary to conduct experiments and evaluations. Don't tell them in advance it is going over, though.

Dr. COOPER. One thing that you can say, Mr. Nelson, is that one could expect no damage to anything on the surface from the overpressures that one might expect from a hypersonic vehicle flying above 150,000 feet.

Mr. WILLIAMS. A good example is the space shuttle. I believe, if I remember the numbers, it is about 0.65 psf at about 130,000 feet. Those of you who have witnessed the space shuttle returning can decide for yourselves whether that would be objectionable to you.

Mr. NELSON. That is what I was going to say. In my part of the country, when we hear that bang-bang, we know the shuttle is coming home, and we like that.

Why don't you characterize the maturity of the various technologies that you have talked about here?

Mr. WILLIAMS. The materials technology, we believe, is quite mature to the extent that it can be put into production fairly soon for even these more exotic materials.

The computational capabilities I spoke to, the fluid dynamics, is very mature. It has been developed over 15 years of intensive work.

The cryogenics, the fuel management technology is also quite mature.

The avionics we are flying today—I hesitate to use the word intelligent—but we are using adaptive flight control computers on

current DARPA programs. For example, our X-29 forward swept wing program is flying very successfully with an adaptive computer generically similar to what we would fly in an aerospace plane.

Of that list of technologies I have gone over, the last one, the long pole in the tent, is the propulsion technology. While 1,000 tests of scramjets gives one a lot of good feeling, it is not until we actually build full scale engines and test them over a couple of years here that we will be able to say that one is mature enough to go ahead.

However, we are excited. We don't see any show stoppers there.

Mr. NELSON. By the way, that forward swept wing was the hit of the Paris air show. It, of course, didn't fly there, but they had a mockup of it along with all the other static displays, and it always had the longest line of people.

Thank you, Mr. Chairman.

Mr. BROWN. Gentlemen, this program is one that has certain institutional complexities. As it has been described, it is going to involve cooperation between the Government and the industrial sector. Some distribution of costs probably will be involved at varying points along the line. It involves several different Government agencies, NASA, DARPA. We heard testimony yesterday that the SDI office is funding some of this research. It also involves several subcommittees and committees of the Congress.

How can we best make sure that all of these different institutional aspects are being treated in a unified way and we are not getting some perturbations that may affect the program?

Dr. COOPER. That is a very astute question, Mr. Chairman. It is a very complex program from the standpoint of the number of organizations who have shown an interest and who would like to participate. I would like to point out, though, that for the time being, only ARPA and NASA have any significant resources invested in the technology development in this program.

We have talked with the Air Force and the Navy. We intend to talk even to the Army about this program. We have enlisted the support of the President's Science Adviser, and he has given us enthusiastic support, but of course the science adviser has no funds to avail us. So, currently, the financial support of the program rests entirely at DARPA and at NASA.

In order to start up a program of this magnitude, several hundred million dollars to do the engine and other technology development over the next 2 to 3 years and perhaps $1 billion or multibillion-dollar level expenditure to take this technology into a flight demonstration phase is going to require a great deal of consensus within the Federal Government and probably large scale funding from the military departments who are the only ones who can support expenditures at this level unless there is a national mandate perhaps for NASA to take the lead in this area.

So, we face—by we I mean they—face some considerable complexity in trying to draw the interest within the Federal Government and in the aviation community generally into this program in a way where everyone is cooperating and contributing what they can by way of resources to the forward motion in the program.

So, that is a problem that we haven't solved at that scale. Bob Williams has done a great job up to now at marshaling forces on

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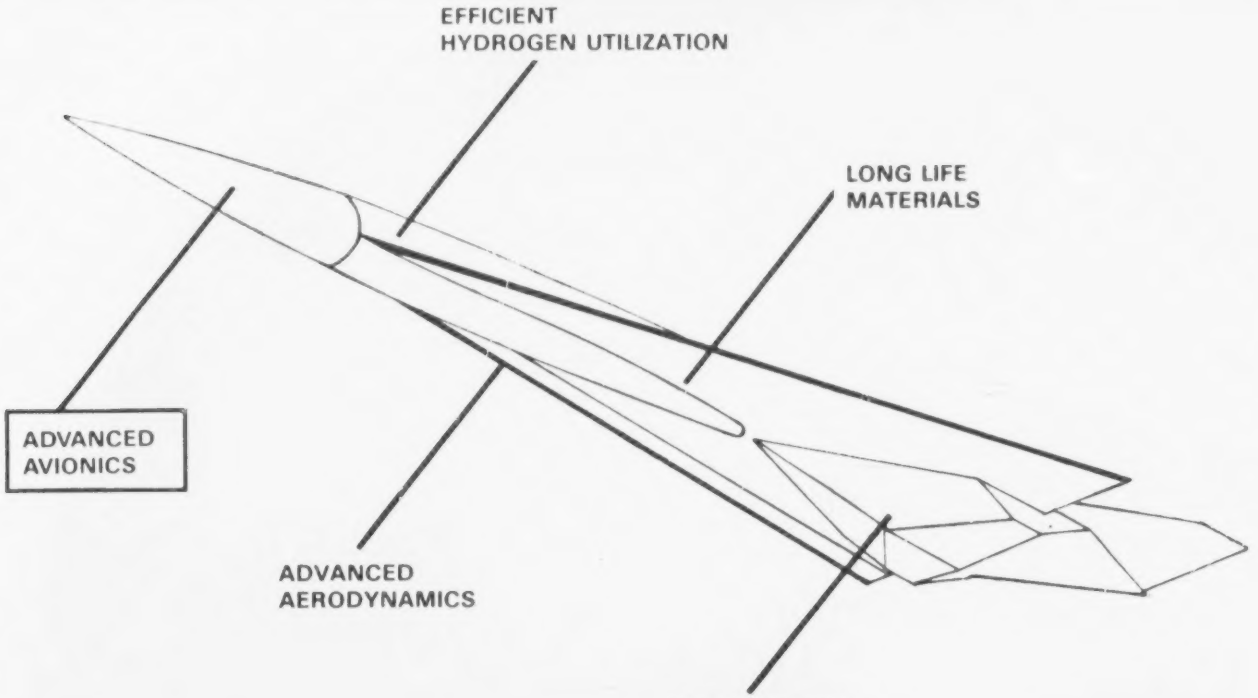
(U) KEY AERO-SPACE PLANE TECHNOLOGIES



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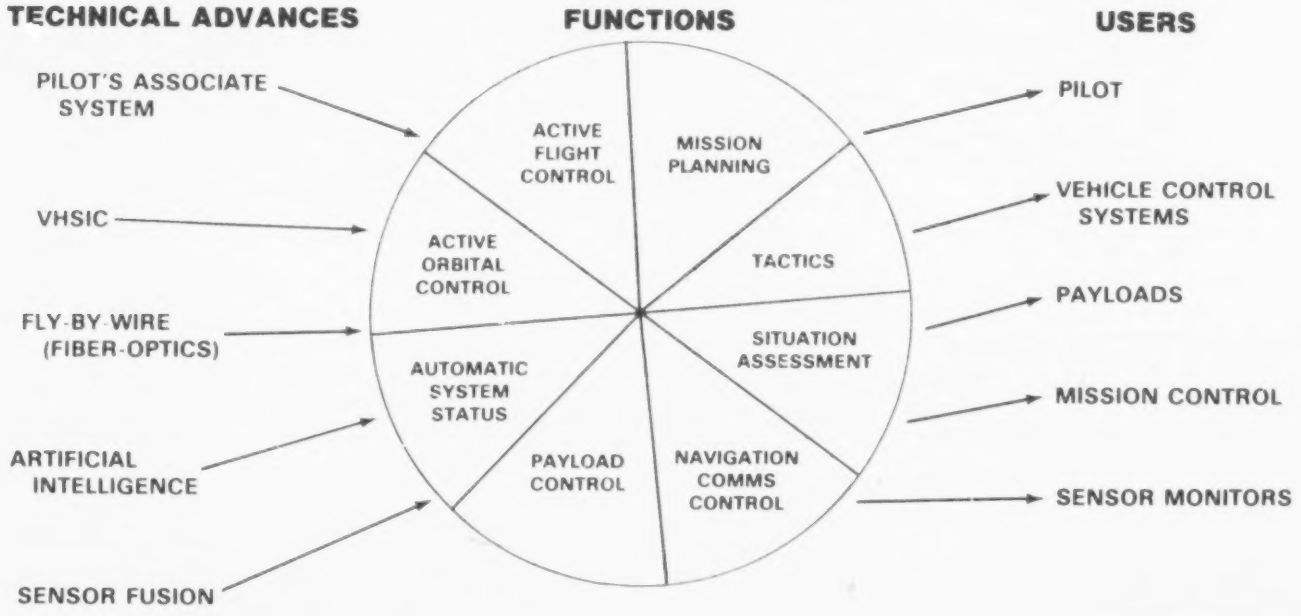
(U) ADVANCED AVIONICS

FULLY AUTOMATED VEHICLE MANAGEMENT SYSTEMS



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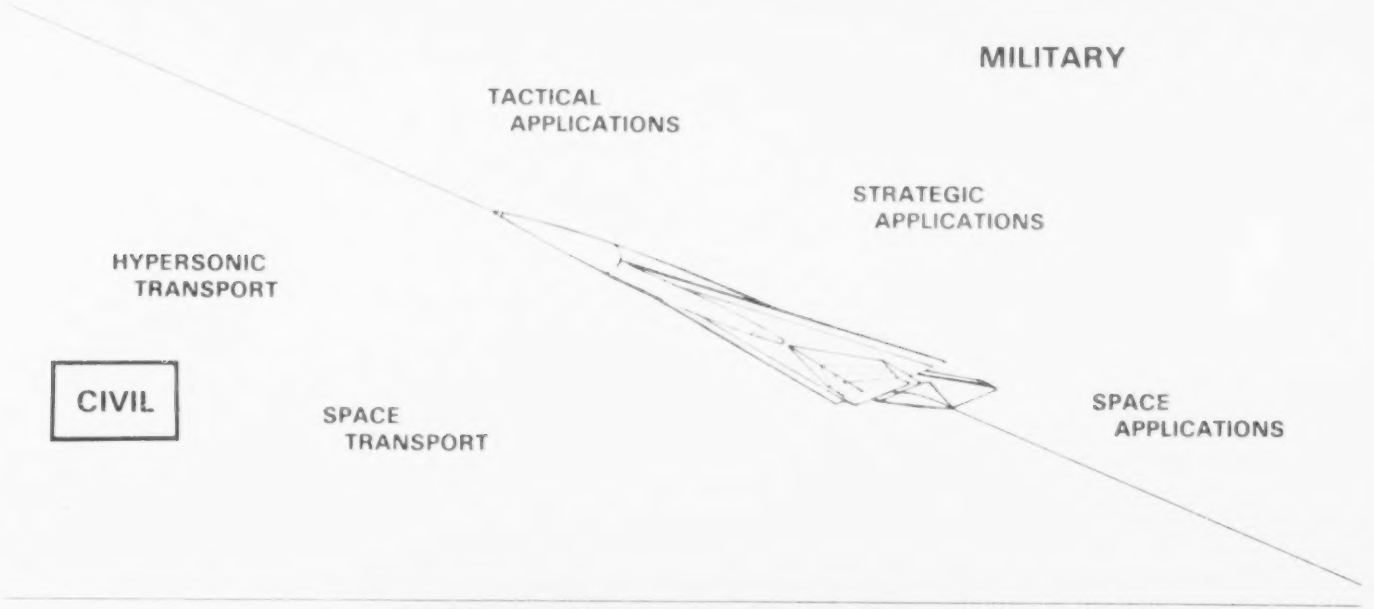
(U) AERO-SPACE PLANE FOCUSES OUR TECHNOLOGY INTO GLOBAL AEROSPACE PREEMINENCE



"SUCCESS IS EIGHTY PERCENT WORKING ON THE RIGHT OBJECTIVE"

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the small scale to work on technologies at about the $10 million a year level. But to go to the next level which is going to be to the $100 million a year level, we still have some institutional and organizational and financial problems to overcome.

Mr. BROWN. These problems, of course, stem from different concepts of what the mission is. DARPA, obviously, is interested from the standpoint of military application. The subcommittee is more interested in the civilian transport application. The SDI office is interested in the problem as it affects the cost of transporting large loads into space, as is NASA, of course, also.

These different sense of missions should serve as a strengthening factor, not as a weakening factor if they are properly integrated. That is a problem that I think requires some thought.

I assume that the numbers of the relevant congressional committees aside from this, the Armed Services Committee and perhaps others, the Appropriations Committee, need to be instilled with a similar enthusiasm about the overall prospects of this program, and I have absolute faith that you are thinking about this problem and how to generate that kind of enthusiasm on a broader basis throughout the Congress. Of course, that requires that you have a coordinated executive branch program to do that.

Did you wish to ask some questions, Mr. Packard?

Mr. PACKARD. No, thank you.

Mr. BROWN. All right. Gentlemen, we thank you very much. We are very impressed with your presentation.

Our next witness is Dr. Raymond S. Colladay, Associate Administrator, Office of Aeronautics and Space Technology from NASA.

STATEMENT OF DR. RAYMOND S. COLLADAY, ASSOCIATE ADMINISTRATOR, OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. COLLADAY. Members of the subcommittee, I am very pleased to be here today for several reasons. First, while I have appeared before this subcommittee on many occasions in the past in a different capacity, this is my first appearance before you as the Associate Administrator for Aeronautics and Space Technology. I expect that we will continue to have the same close and productive working relationship as we have had in the past as we chart a course for the NASA aeronautics program together in the future.

I am also especially pleased to be here because of the topic of the hearings this morning. I try to maintain a healthy disregard for the impossible, and with the progress we have made over the last few years, I think the time has indeed come to seriously consider and, even more than that, seriously move out in developing the technology for sustained hypersonic and transatmospheric flight.

As has been pointed out on occasion this morning from Dr. Cooper's statement and Bob Williams, NASA has played a major role in developing the technology. We will continue to do that and, in fact, build up our efforts as we coordinate and focus on this program that Bob Williams described for you this morning.

It has the advantage of straddling both aeronautics and space technology and pulling them together which is an important element of the program and one that I think NASA stands in a par-

ticularly unique position to finally get these two subjects pulled together as they should be. We do in aeronautics look at the shuttle as an airplane, and we use it, as I will point out later in my statement, as a research vehicle for aeronautics and for hypersonic flight.

With your permission, Mr. Chairman, I would like to submit my written testimony for the record and proceed to summarize the main points.

Mr. BROWN. Without objection, so ordered.

Dr. COLLADAY. Before I do that, I would like to introduce Ms. Lana Couch whom I have recently named to a special assignment as manager of the Hypersonics Transatmospheric Program at NASA. In that capacity, she reports directly to me and has both space technology and aeronautics under her direction in those areas that are applicable to this subject.

Mr. BROWN. We are very pleased to have her here this morning and to give her due recognition for that important assignment.

Dr. COLLADAY. She is my champion for this subject. If you question her resolve on the subject of hypersonics just challenge her. She is a very dedicated program manager.

We have long had a goal of developing a hypersonic airplane or transatmospheric vehicle with the ability to take off from a conventional runway with airbreathing propulsion, accelerate to hypersonic speeds in excess of mach 6 to even near orbital speeds of mach 25 and on into orbit, maneuvering in and out of orbit, and landing at a conventional runway.

Is that a pipedream? I don't think it is. We have talked about the things that have changed that give us the confidence that this is possible, and I think there are really three things that naturally have to come together, and are coming together at this point in time. One, and certainly the most important, probably, is the maturation of the technology. We have heard, and I will show, that technology is coming to a point where we are confident that we can take the next step.

That has to be combined, however, with a demonstrated need for that capability and a national commitment or a national will to take the next step. That consensus I see in a number of areas, most notably this hearing this morning, as happening, and I am encouraged by that. I feel certain that sustained hypersonic flight is feasible and that we will encounter no show stoppers, but it won't be accomplished without considerable challenge, but it is the kind of challenge that I think together, with the combined efforts of private and public sector, we can make it happen.

As you are aware and has been pointed out, NASA has a long history of interest and involvement in hypersonic and transatmospheric vehicle technology. It started back in the late 1950's with the X-15 Program and Scott's efforts and the research in that effort at Edwards. It was followed by the hypersonic research engine that Bob Williams pointed out this morning. That was tested at the NASA laboratories and ground tested with the intent of integrating it on the X-15 and getting some flight data.

Well, that didn't happen, but in the same time period, we were developing lifting body technology which gave us a rich data base in entry vehicle technology that later spun off and was incorporat-

ed in the shuttle design. We were planning a National Hypersonic Flight Research Facility in the late 1960's in what we call the NHFRF program with the Air Force, but that reached only a planning stage and we did not go forward.

That ushered in the age of the shuttle and the decision to go ahead with the development of the orbiter. That is an excellent data base or vehicle by which we can get some valuable hypersonic flight data. It doesn't have the kind of cross range, maneuverability, and sustained hypersonic flight in the atmosphere that we are talking about here, but we are using it, as I will point out, as a research airplane to get some valuable data.

We also have maintained the nation's R&D base progress in the area of hypersonics and scramjets—supersonic combustion ramjet—high temperature structures and materials, and aerothermodynamics and, to the extent that the program has provided a nucleus, have maintained the nation's core of skilled personnel in hypersonics. They have begun to dwindle away, particularly in private industry.

We also have unique facilities which we are reactivating and, in some cases, upgrading to bring to bear on the ground testing that Bob Williams referred to.

NASA's research effort has been continuous over the last 10 years in base technology. It has moved at a deliberate if not slow pace. It has made progress, and it is largely on the basis of that progress that we have confidence now to move ahead. We persisted in that research even during times when it was not fashionable to do so, but I think it is a clear example of where NASA aeronautics base technology can keep pushing the frontiers of research even when it isn't associated with a major thrust and focused effort which we now see hypersonics becoming.

From the background of research that we have been pursuing over the last 10 to 15 years, we have identified the key technology areas that represent, as Bob said, the long poles in the tent. He covered them ably this morning. Just to review for you briefly what they are, propulsion is the key as are aerothermodynamics, and controls. Hot structures and materials, the system integration of the propulsion in the airframe is crucial.

Air-breathing propulsion is the key technology we feel. The characteristic of a propulsion system is that it needs to accelerate from a standstill, zero start to high velocity. It must have high specific impulse in order to minimize fuel consumption and operate over a wide speed range, from zero to—if we are talking about transatmospheric flight—even up to mach 25.

There is no one single propulsion system that can accomplish that. The objective of this early technology effort is to sort out the preferred path on the propulsion systems.

Probably the clearest and least ambiguous propulsion regime is the most difficult or most challenging, and that is the area of mach 6 and above where the scramjet performance is optimum. We don't know what the upper envelope of that speed range is, and we will be exploring that in the program in the coming months and years.

We have had a great deal of success in the scramjet technology at Langley in the mach number 4 to 7 range. Currently, the ground based facilities limit the testing to mach 7. With facility modifica-

tions that we are planning now, we expect to be able to ground test full scale propulsion system modules up to mach 8. Beyond that, we will have to do flight research of the schemes beyond mach 8.

Engine integration is another key area that requires extensive wind tunnel testing and perhaps flight testing. The inlet area, capture area of the engine, represents as much as 50 percent of the frontal area of the vehicle, and the nozzle is the entire aft end of the vehicle or expansion surface. So, you can't talk about propulsion in the high hypersonic range without getting into vehicle design, and the two are very closely related.

The emphasis in the very near term must be on the propulsion concepts below mach 6 where multiple or combined or hybrid systems are likely to be required. Since scramjet propulsion will not operate below mach 4, we need to develop a multiple or combined system that would perform effectively from zero mach number to the range of 5 or 6. A number of concepts that I think the industry witnesses will be describing for you after my testimony will be explored.

Other key areas are structures and materials which DARPA discussed previously as well as controls, and I won't go into them in any further detail.

Aerothermodynamics and computational capabilities are key as was pointed out. Understanding chemical reacting boundary layers and catalytic surface effects is crucial because of the heat loads on transatmospheric application and upper atmosphere conditions and constituents above 200,000 feet are virtually an unknown. Although for each trajectory of the shuttle we are collecting data, but it is a single path entry, and we need to collect more information on the upper atmosphere.

Those are the key half dozen technologies. Not surprisingly, they are the five or six that the NASA program has been exploring and will with increasing emphasis explore and develop in the future. Scramjet research, the low velocity propulsion, configuration aerodynamics, orbiter data base, the facility modifications that we have made, and university programs are the thrust of the program that is being focused on the coordinated effort that we are describing for you this morning in the DARPA/NASA effort.

As I pointed out, there has been significant accomplishment in the last few years on the supersonic combustion ramjet up to mach 7. We are testing full scale flight hardware of the fuel injection strut of that engine, because it happens to be structurally the most hostile environmental condition that the engine faces.

We will be testing that module in the near future. It is under fabrication now. We have done a number of scale model tests of the whole module, and that represents the cumulation of the 1,000 tests of the scramjet configuration that Bob Williams referred to.

We have been exploring in that time and developing the data base for combustion kinetics and tailoring the design to optimize the configuration of the scramjet. We will be scaling up those modules to full scale and testing in the modified 8-foot-high temperature tunnel at Langley which is a construction of facilities project currently underway.

We have a joint program that we are going forward with on the mach zero to 6 propulsion system with DARPA that will be a con-

tracted effort. We will be releasing a request for proposals soon, and it will be a competitive effort and underway, hopefully, by the first of the year.

The configuration that will be the result of that contracted effort will likely be tested in the new upgraded Propulsion Systems Laboratory at Lewis Research Center.

We have had underway and continue——

Mr. BROWN. Dr. Colladay, we have a rollcall on, and I think we would like to go vote. Can you suspend at this point?

Dr. COLLADAY. yes.

Mr. BROWN. We will recess for about 10 minutes and return as quickly as we can. The subcommittee will be in recess.

[Short recess taken.]

Mr. BROWN. The subcommittee will reconvene, and we will continue with the testimony of Dr. Colladay.

Dr. COLLADAY. Thank you, Mr. Chairman.

I was just summarizing the current program emphasis and where I see us going in the future, and I was describing the NASA industry study in the mach 4 to 5 range that we have had underway since 1982 to determine propulsion airframe integration and configuration issues. The results led to wind tunnel tests that we did on a number of configurations that have built a rich data base for that speed regime and the inlet which is always one of the complex elements of the propulsion system. The inlet is to be tested at Lewis about 1 year from now. We are in fabrication of the hardware at this point.

I mentioned the shuttle as an airplane, and that truly is the way we have looked at it in aeronautics and space technology. We are getting valuable data on every single shuttle flight that has gone up on the boundary layer effects and heating and upper atmosphere constituents.

We have an extensive instrumentation package on Columbia that has just been returned to the Cape for a launch in December the way it looks now. It includes more instrumentation relevant to hypersonic flight than we have had on any other vehicle. It has an entry air data system that will give us data on the upper atmosphere that we have never had before. There is an upper atmosphere mass spectrometer on board that will give us valuable data, accelerometers, an infrared radiometer package that will look at the lee side heating on the vehicle.

Those data together with the data that we have from earlier shuttle flights are going to give us a valuable hypersonic data base but still only a single trajectory through the atmosphere, not extensive enough to completely answer the questions that we have.

Facilities are a key, and we have underway modifications to the 8-foot-high temperature tunnel at Langley. That tunnel is being enriched with oxygen so that we can test full-scale supersonic combustion ramjet engines in the wind tunnel. That was in the 1985 request for construction of facilities, so we anticipated this need back in 1983 when we brought that project forward in our budget request. The timing is perfect now for moving out in the important propulsion area that we have been discussing.

I mentioned briefly the Propulsion Systems Lab at Lewis, and we are making modifications to that engine test chamber to evaluate

the combined and hybrid propulsion systems that we have been discussing this morning.

We are reactivating the 3.5-foot hypersonic wind tunnel at Ames for the aerothermodynamics work.

As valuable as those facilities are, however, and as crucial as they are, flight testing of configurations will be necessary. We recognize that; our facilities will be limited to mach 8 approximately.

No undertaking like this would be possible without the talent of engineers and scientists that have training in the field of hypersonics and high-speed flight. NASA has retained a number of the people who have been involved in the program for many years. Mrs. Couch is one of them. She came from Langley and has been with me in headquarters for the last 5 years, I believe.

The research people at NASA are very excited about this program and are eager to get underway with the expanded effort. That alone, though, is not enough. We need to look to training new engineers.

With that objective in mind, we have teamed with the Office of Naval Research and the Air Force Office of Scientific Research to sponsor and initiate a new research grant program with universities in hypersonics. In addition to the research output that we know will come from that effort, we will also be training new students and universities will be developing the curriculum that will be focused on hypersonic flight. I think that obviously is an important part of our long-term effort in this area.

In summary, I would like to just comment that I feel certain that sustained hypersonic flight in the atmosphere and transatmospheric flight is technically feasible. Because they are, I feel certain that they will happen. The question is just one of timing. It will take a national commitment. It will be expensive. And to prove the technology, we are going to need to go to a flight demonstration vehicle that will follow a ground base technology effort.

DARPA and NASA have demonstrated an ability to work together. We depend on and compliment each other. I think we have demonstrated that that makes a powerful Government team and that, combined with industry and universities, I think, will provide an impressive national team that can undertake successfully this initiative and this effort. We stand ready to support it in technology and in people and facilities in NASA, and I think the time is now to get on with it.

Thank you.

[The prepared statement of Dr. Colladay follows:]

NASA
National Aeronautics and Space Administration

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Presented by Witness

July 24, 1985

Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology

House of Representatives

Statement by:

Dr. Raymond S. Colladay
Associate Administrator
Office of Aeronautics
and Space Technology

99th Congress

HOLD FOR RELEASE UNTIL
PRESENTED BY WITNESS
JULY 24, 1985

STATEMENT

OF

Dr. Raymond S. Colladay
Associate Administrator for
Aeronautics and Space Technology

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Transportation, Aviation
and Materials
Committee on Science and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee,

I am pleased to testify before the Transportation, Aviation and Materials Subcommittee on NASA's research in the hypersonic and transatmospheric flight regimes. My testimony will cover very briefly, NASA's past involvement in hypersonics research, the enabling technologies required to achieve sustained hypersonic and transatmospheric flight and some specifics of NASA's ongoing research in these areas. Your request in the FY 1984 NASA Authorization for the "Focussed Hypersonic Research Program" report which we submitted last year and the recent Office of Science and Technology Policy (OSTP) National Aeronautical R&D Goals report have aided significantly in our planning for future research activities.

Advances in technology will permit development of vehicles with new, and perhaps revolutionary capabilities. Hypersonic vehicles for space applications are possible that have operational scenarios typical of aircraft. These vehicles could quickly takeoff from conventional airports, fly to orbit with high priority cargo, maneuver extensively within the upper limits of the atmosphere, and then return to land at an airport of choice anywhere in the world. Rapid transportation between earth locations could be possible using vehicles that cruise at hypersonic speeds within the atmosphere while retaining the utility and operational features of conventional transports. The technical challenges for such vehicles are formidable and long lead times are to be expected; however, there is no question as to the feasibility of eventually achieving technology readiness. The key to realizing these possibilities within the foreseeable future is the pace of the technology program.

NASA has a long standing history of interest and involvement in Hypersonic and Transatmospheric vehicle technologies. This involvement can be traced back to the X-15 program in the late 1950's and 1960's which began the exploration of flight in the hypersonic speed range. The NASA Hypersonic Research Engine (HRE) program of the

mid-1960's validated the technology for a hypersonic airbreathing propulsion system through ground tests; planned flight tests of the HRE on the X-15 did not occur. The DynaSoar and lifting body programs of the early 1960's expanded the technology available to designers of lifting entry vehicles. In the mid 1970's, the lifting body programs also served to stimulate a cooperative activity between NASA and the USAF to develop a National Hypersonic Flight Research Facility (NHFRF) for exploring propulsion technology and other challenges associated with flight at Mach 7. Unfortunately the NHFRF program never matured beyond the planning stage. The Space Shuttle, however, marks a major milestone in the history of hypersonic flight. The Shuttle flight data, which have validated a broad technology base over a limited flight corridor, demonstrate the potential for a wide variety of new capabilities in hypersonic/transatmospheric flight.

Throughout the period from the late 1950's until today, NASA, as part of its responsibilities to conduct research in aeronautical technologies for the future, has sustained a level of research activity in the most critical of the enabling technologies for sustained hypersonic flight. This has resulted in major advancements in airbreathing propulsion, structural design and aerodynamic configurations and has thus maintained a core of skilled personnel with the expertise needed to address the required technologies for future advances in this flight regime.

The Focussed Hypersonic Research Program report prepared by NASA and submitted at your request last year, contains the elements of a Hypersonics and Transatmospherics research and technology program consistent with the long-term National Transatmospheric objective stated in the March 1985 OSTP Report on National Aeronautical R&D Goals. The Transatmospherics goal proposes a technology program to secure national options for a broad spectrum of capabilities: rapid response to low earth orbit, maneuvering into and out of the atmosphere, and long-range, high-speed cruise in the atmosphere.

ENABLING TECHNOLOGIES

The capabilities envisioned will lead to vehicles for sustained operation in the atmosphere and space and transition between the two, thus forcing the technologies to levels of integration beyond those possible in the traditionally separate aeronautical or space disciplines. Within this framework, major advances in propulsion, structures, materials, controls, systems integration and other key technologies are required to enable these capabilities.

The pacing requirement for very high speed flight in the atmosphere is the development of airbreathing propulsion technologies. The airbreathing propulsion system must provide for self acceleration from takeoff, have high specific impulse to minimize fuel usage, and operate over the entire operating speed and atmospheric envelope of the vehicle. In addition, the extremely high temperatures that a hypersonic engine will experience and the integration of the inlet/nozzle into the flight vehicle present significant challenges. As an example, the inlet/engine/nozzle integration presents new problems -- the inlet capture area may be 50 percent of the total frontal area of

the vehicle and the nozzle may comprise the entire aft end of the vehicle as an expansion surface. Integration is clearly of major importance and will be the dominant factor in configuration development; in fact the inlet engine/nozzle arrangements will largely determine the vehicle aerodynamic configuration since the forebody is part of the inlet and the afterbody is the nozzle.

Since no single propulsion concept or system has yet been identified that can cover the entire speed range from takeoff to orbital velocities, some form of multiple, combined, or hybrid system will be required. A multiple system relies on two or more separate engines to span the mission speed range; a combined system integrates the features of two or more airbreathing types of engines into a single system. A hybrid system integrates a rocket engine with or into an airbreathing system. An example of a multiple system is an over/under stacked turbojet/ramjet propulsion unit; an airturboramjet (ATR) is an example of a combined system.

For operation at speeds below Mach 6, the optimum cycles have not yet been identified or selected. Consequently, there is much work to be done in evaluating and characterizing the many propulsion candidates for this speed regime. Cycle analysis studies, component design and evaluation, and validation testing must be conducted to permit selection of the particular designs to pursue into larger scale development.

For the speed regime above Mach 6, the only viable airbreathing propulsion system is a supersonic combustion ramjet (SCRAMJET). NASA has been working on the hydrogen fueled SCRAMJET for the last 15 years as the most critical technology for hypersonic flight. Progress has been steady, and practical levels of net thrust have been demonstrated at Mach 4 and 7 in the Langley SCRAMJET Test Facility. This capability is the key to sustained hypersonic flight above Mach 6, and we are developing a performance and structural design data base for a single integrated engine design covering the Mach 4 to 7 speed range. Although an upper speed boundary of the SCRAMJET has not been identified, the physics indicate that there is a potential for SCRAMJET operation at much higher Mach numbers. However, there are no ground facilities adequate to support the required testing range and the upper speed boundary will have to be investigated through flight research.

The selection of propellants and fuels is critical to operation of the propulsion system and design of the airframe. NASA has concentrated on liquid hydrogen as the fuel of preference since it places no constraints on the upper Mach limits of the propulsion system; it has high specific impulse, large heat sink capability and a combustion process well matched to SCRAMJET requirements. In addition, the logistics and operating experience are such that the use of liquid hydrogen can be considered well within the state-of-the-art. NASA has studied other fuels, such as methane, which are usable for specialized applications, but they are limited to a much narrower speed range.

Structures and materials requirements for hypersonic applications are extremely demanding not only for the propulsion system but also for the airframe. The airframe structure requires long life, complete

reusability, all weather operation, and low weight. For some missions, the total structural heat load accommodation will dominate the design rather than only the maximum (or peak) surface temperature as is the case with the relatively shorter hypersonic flight duration of the Shuttle. As a result the thermal stresses resulting from combined peak and total aerothermal loads assume much greater importance in designing the structure. Regenerative cooling concepts and better insulators will be required to avoid heat transfer to the substructure, payload, fuel tanks, and cabin environment. Large reusable cryogenic tanks for liquid hydrogen (LH_2) have never been flown operationally; only one has been fabricated. Our program is addressing many of these requirements through basic research efforts which are generally focussed on small scale specimens and components. Advancements in analytical tools, materials, and structural concepts must be validated with ground tests of large-scale components and flight tests of selected full-scale components and systems.

Virtually all of the suggested hypersonic cruise transatmospheric applications presuppose a high level of autonomy in flight. Advanced control and guidance concepts that accommodate highly interactive aerodynamic and propulsion controls will be required. Some relevant concepts and techniques will evolve from on-going R&D in high performance aircraft, the Space Shuttle, and the Space Station. However, the high operating temperatures of hypersonic vehicles will pose new challenges to designers of hydraulic, electrical, environmental control, and other critical subsystems.

Substantial progress has been made in the past several years in computational methods for aircraft aerodynamic and aerothermodynamics parameters, and the Shuttle has provided a great deal of validation data. However, the ability to confidently predict the flow-fields and the aerothermodynamics of complex configurations over a broad Mach number range is still limited. Understanding the chemically reacting flow-fields, catalytic surface interactions, boundary layer transition phenomena, and the effects of atmospheric density variations which occur above 200,000 feet is essential for minimizing thermal protection requirements, overall system weight and establishing control margins.

RECENT NASA ACTIVITIES

NASA has responded to a request by the OSTP to develop technology roadmaps to support the three National Aeronautical R&D goals and the Hypersonics/Transatmospherics goal is a major element of that activity. These roadmaps are being further developed in coordination with industry and DOD to identify technology requirements as well as program content, schedules, and resource levels necessary to meet the goals. This activity, together with the Focussed Hypersonic Research Plan, will provide guidance for the future direction of NASA's technology program. At the present time, there are significant NASA activities in SCRAMJET research, a joint engine program with DARPA, Mach 4 to 5 airplane concepts, an Orbiter experiments program, facility modifications, and a new university research program.

SCRAMJET research is continuing in the areas of combustion processes, computational techniques, engine module geometry effects, and propulsion system experiments. In addition we are addressing the most critical thermal structural design problem -- that of the device used to inject fuel into the engine for combustion -- the fuel strut. A flight weight model of the fuel strut is being fabricated for experimental validation of the predicted performance.

A cooperative program between DARPA and NASA is being initiated that will develop a data base for a combined cycle airbreathing engine. The competitive procurement will be a multiphased effort that will lead to development of a selected engine concept and ground testing at Mach 5 to 6 in the Lewis Propulsion System Laboratory. The Request for Proposals will be released this summer with award of a contract by the first quarter of 1986.

In the 1982 to 1984 time period NASA, with industry participation, conducted a study, directed at Mach 4 to 5 airplane concepts. The primary emphasis was on evaluating various vehicle concepts to determine the major technology drivers for a hypersonic cruise airplane. The results clearly identified airframe/propulsion integration as the key to achieving acceptable performance. As a part of this program, several wind tunnel models with many geometric configuration variables were fabricated and tested to develop a data base for future studies. The propulsion concept that evolved from the study was an over/under propulsion system using a conventional turbojet for takeoff and acceleration and subsequently transitioning to a RAMJET for high speed cruise. A variable geometry, two-dimensional inlet design for this concept was completed and a model is under construction. This inlet model will be tested in 1987.

The Orbiter Experiments (OEX) program is also producing data of importance to hypersonics and transatmospherics. Results of current and upcoming Orbiter experiments will serve as a benchmark data base for development and validation of aerodynamic and aerothermodynamic prediction techniques. In addition, information on upper atmosphere constituents, plus evaluations of some advanced thermal protection system concepts, will be useful in increasing our understanding of materials behavior.

Ground facilities are essential for continued progress in this area. In order to enhance our capabilities we have begun to install advanced instrumentation in existing facilities. In addition major facility modifications are planned to permit: full scale verification of SCRAMJET combustion systems in the 8 Foot High Temperature Tunnel at Langley Research Center, testing of combined cycle engine concepts in the Propulsion System Laboratory (PSL) at the Lewis Research Center, and flow-field studies in the reactivated 3.5 Foot Hypersonic Tunnel at Ames Research Center. However, the range of existing and modified ground test facilities will remain limited, compared to the capability needed to develop the data base for evaluation and verification of theory and advanced concepts. Therefore, as noted previously, flight testing will be required for propulsion, structures, and airframe systems validation and/or verification.

In order to develop a new generation of hypersonic technologists, NASA, ONR, and AFOSR have joined to initiate a new research grant program at three universities in FY 1986 in the area of hypersonic viscous flows. We expect that this program will stimulate students to focus their studies on fundamental problems in hypersonics and aerothermodynamics, and provide an incentive to the universities to develop the necessary associated curriculum. The development and training of talented students is an essential step to more aggressive, sustained long term progress in this field.

SUMMARY

Hypersonics/transatmospherics flight is an area of great challenge and potentially high payoff to the Nation. Significant advances must be made in airbreathing propulsion to enable advanced engine cycles and design data to match the requirements of specific vehicle applications. New thermal/structural design concepts that can support the high temperatures and extended life requirements inherent in reusable vehicles must satisfy stringent weight constraints.

Validation data will be critical to maturing some of the technologies, requiring ground tests of large-to-full scale components and flight research in selected areas. For example, since these vehicles will be highly integrated designs, the entire vehicle concept could be unacceptably compromised through a build-up of small design tolerances. Therefore, a flight research aircraft or at least flight testing of major components and systems will be required to successfully reduce the design margins.

Above all, a sound research and technology base in all disciplines must be provided to support the very broad ranging nature of the hypersonic/transatmospheric flight regime. With its unique facilities and solid core of professionals dedicated to research in these areas, NASA is in a position to provide the leadership for a national technology program if the decision is made to initiate one.

Mr. BROWN. Thank you very much, Dr. Colladay.

Do you wish to make a statement, Ms. Couch?

Ms. COUCH. No, I don't. I have no prepared comments.

Mr. BROWN. I think NASA deserves a great deal of commendation for maintaining the level of research programs both at Headquarters and at the laboratories in this area. In hindsight, we probably would have wished that they had maintained an even stronger program, but under the circumstances, I think we owe a debt of gratitude to them for keeping alive the fundamental research in this area and continuing to pursue it which enables us to make some of the decisions today about where we go into the future.

In connection with your statement about close cooperation between you and DARPA and possibly other agencies, to what degree is any of the NASA research program in this area or in any of these technologies supported by passed through funds by any of these agencies or are you doing it entirely out of your own budget?

Dr. COLLADAY. No, it is not entirely out of our own budget. There is a pooling of resources as occurs naturally when we focus our efforts consistent with the program requirements. I will say the program that we have been talking about this morning. For example, the propulsion contracted effort will have funds from both NASA and DARPA. I think, as we proceed with an expanded program, you will see resources from both NASA and DARPA, in some cases where NASA would use DARPA resources in the management of the technology efforts.

So, it is a truly integrated program effort that we are planning.

Mr. BROWN. Mr. Packard, do you have any questions at this point?

Mr. PACKARD. Yes, thank you, Mr. Chairman.

In your statement, you say NASA has studied other fuels but primarily you use liquid hydrogen, according to your testimony, but you have studied other fuels such as methane which are usable for specialized application but are limited to much narrower speed ranges. Would you elaborate on that and indicate the limitations of methane as compared to liquid hydrogen?

Dr. COLLADAY. Yes, Mr. Packard, we have looked at methane and hydrogen. Most of our research in the supersonic combustion ramjet engine has been with hydrogen. Methane is also an attractive fuel. It does have limitations at high mach numbers above mach 5, say, because of the limited heat sink capacity of the fuel.

Aerodynamic heating and the propulsion system will require fuel cooling, active cooling, using the fuel as a heat sink, and methane above mach 5 would not be suitable for that purpose, whereas hydrogen has a much greater heat sink capacity. So, the narrow window is perhaps not so narrow if you look at it in terms of the overall mach number range. It is essentially zero to mach 5 would be an applicable range for methane, whereas hydrogen is applicable from zero to transatmospheric speeds.

Mr. PACKARD. Are there other significant changes that take place between mach 5 and mach 6 area that have to be addressed other than the fuel applications? Are there significant differences in conditions between the supersonic and the hypersonic?

Dr. COLLADAY. Not any other major differences between mach 5 and mach 6. We have talked about mach 4, a range of 4 to 7. We

have talked about mach 6. We have talked about mach 5. Let me try to put all those in some perspective.

The air turbo-ramjet and other combined cycles of propulsion systems are generally applicable from zero to about mach 5 to 6. That is one range. From the top, scramjet propulsion systems are effective maybe down to mach 4, so you have an overlap up to mach 6 and down to 4. Mach 5 is about the limit right in the middle for methane applications from the heat sink standpoint. We have tested the scramjet propulsion system in the range that we have facility capability up to mach 7, and they are only good down to mach 4, so that gives the range 4 to 7.

Mach 7 is only a limitation, as we see it now, in facilities that we have had up to this point. We don't know how high the scramjet propulsion systems will be applicable.

Mr. PACKARD. So, structurally and the protective mechanisms within the structure of an aircraft are not substantially different between your different mach ranges, particularly in the higher ranges?

Dr. COLLADAY. Well, aerodynamic——

Mr. PACKARD. Do you have to do what you do on, for instance, the space shuttle in order to protect it from heat as is moves in and out of the atmosphere, and so forth?

Dr. COLLADAY. The shuttle is designed to accommodate peak heat loads. Transatmospheric vehicles that would maneuver in the atmosphere at sustained hypersonic speed would, in addition to high peak heat loads, have to be designed to accommodate long soak times, that is long periods of time at a high heat load. That puts new design challenges on the configuration so that it would likely such a vehicle would have to be actively cooled as opposed to just thermal insulation.

So, as you go up in velocity, the aerodynamic heating goes up, and the demands on the configuration resulting from that are clear.

Mr. PACKARD. Mr. Brown brought up with an earlier witness the question of ground facilities. You allude to that briefly by saying there are no ground facilities adequate to support the required testing range in the upper speed boundary. What kind of ground facility changes do you anticipate that is necessary to, No. 1, accommodate the testing and the development of such hypersonic aircraft compared also with that of ongoing production and use of domestic and civil service type of activities? What kind of ground changes would you anticipate would be necessary?

Dr. COLLADAY. I think we either have or will have with the modifications to facilities we are currently making all the ground base facilities that are necessary to ring the feasibility of the aerodynamic structure and the propulsion system. So, I don't see any big facility requirements.

We will never be able to test on the ground the higher speed regimes of hypersonic flight. It would be prohibitively expensive to do that and much more economical and reasonable to do a flight test. So, I think we have within our current inventory in the country the facilities necessary to do this phased technology program leading to a flight demonstration which is going to be required anyway.

Lana, would you like to add anything to that?

Ms. COUCH. The only thing I might add to that is the computational capability complementing the basic facility capability that we have and that we are developing through the modifications that Dr. Colladay mentioned to you. The advances in computational fluid dynamics that have occurred over the last few years and the enhanced computer capability that exists now blends very nicely with the facility capability—particularly with the CFD techniques that we have been able to validate to some extent using shuttle entry data, and so forth. We do believe that the facilities that we have and that we are modifying will be adequate, but the flight testing area is probably as critical or more critical for hypersonic and transatmospheric work than technology work that I can recall on past systems.

There are some additional simpler flight experiments than some of the end product types of things that we have been talking about here that may very well be useful to this program in helping to check out system components on a somewhat smaller scale than going to a total flight vehicle. It certainly wouldn't put aside the need to do a flight vehicle and do flight research on a large vehicle, but in getting to that we can gain a lot by going at it piecewise on some simpler flight experiments, and we are looking at that as part of the program.

So, it is a rather methodical process to reducing the risk of going to a flight research vehicle which we agree is necessary.

Mr. PACKARD. Can a good deal of that be done on the shuttle itself?

Ms. COUCH. Part of it can be, keeping in mind that the shuttle flight path is pretty much a single flight path and the fact that the shuttle does not maneuver extensively at high altitudes. The kind of vehicles that we are talking about, the capabilities that we are talking about here address hypersonic maneuvering in particular. Those are exactly the kinds of capabilities that we are interested in developing along with hypersonic cruise as part of the technology.

Mr. PACKARD. Thank you very much.

Thank you, Mr. Chairman.

Mr. BROWN. You don't encounter any problems with regard to control surfaces, maneuvering capability and so on that is radically different from what the shuttle encounters on its return to Earth, do you, with the hypersonic direct accent plane? Wouldn't they be similar to what you would encounter on the shuttle?

Dr. COLLADAY. Well, the flight envelope is considerably different when you talk about the maneuverability that would be required of a sustained hypersonic flight vehicle, but certainly the shuttle experience has provided a rich data base in support of that design.

Ms. COUCH. In maneuvering in the very low density part of the atmosphere which we might do, say, if you are talking about high altitude flight over 150,000 feet or so, something like that. For example, in concepts where they talk about transatmospheric vehicles going into orbit, deorbit, and then maneuver and do plane changes and reorbit, as you have seen in some of the published articles, there is some question about the aerodynamic controlability in the low density environment. We don't know how much aerodynamic control we would have under those circumstances. It may re-

quire, for example, primarily propulsion control with augmented propulsion systems and so forth.

The low density environment on its own, talking about that for a moment, is an unknown. We don't have a lot of information on the real high altitude environment. There are density variations in that range that look like they are 30 to 50 percent or maybe higher, if I remember the number correctly. We don't know what impact this will have on the controlability of the vehicle.

So, those kinds of aspects have to be taken into account. That is one of the areas where we would very much like to do some simple flight experiments and spend a little time cruising through that environment with the proper kinds of instrumentation on a real small, fundamental experiment type vehicle to get a look at the density and how a vehicle would react to that kind of environment where it would spend a fair amount of time.

Mr. BROWN. What about the problems of maneuvering in space? How do we handle that other than just through propulsion, orbital changes, plane changes, and so on?

Dr. COLLADAY. Maneuvering while in space would have to be by propulsion. Plane changes, however, could be made by deorbiting into the atmosphere, maneuvering, and accelerating back into orbit. But maneuvering small changes while in orbit would obviously require propulsive thrusters.

Mr. BROWN. In addition to the engine itself, you mean?

Dr. COLLADAY. That is right.

Mr. BROWN. What about the inlet configuration problems? Do those pose any insurmountable structural difficulties that change at any particular point in the envelop?

Dr. COLLADAY. No, I don't believe that represents any kind of a show stopper. It is a complex design and configuration because it has to be tailored to the whole underside of the vehicle—the whole forebody of the vehicle is the inlet. But I think with the computational power that we have that Lana referred to and the wind tunnel testing that we can do, I think that is certainly not an extremely difficult problem.

Mr. BROWN. Well, Dr. Colladay, there is a number of other areas that need to be explored here, but we are running out of time. We may ask you to supplement the record with some additional answers if you would be able to do that.

Dr. COLLADAY. I would be happy to do that.

Mr. PACKARD. Mr. Chairman.

Mr. BROWN. Yes.

Mr. PACKARD. Would you permit one last question that I don't think has been addressed yet?

Mr. BROWN. Certainly.

Mr. PACKARD. In your work with the shuttle, have the cabin atmosphere, the pressure, the oxygen, the air quality, et cetera, to accommodate 300 to 500 people, what kind of changes would you experience or would we expect to experience in accommodating 300 to 500 passengers while in a space situation, comparing that with 5 crew members? What kind of problems would we run into there?

Dr. COLLADAY. I don't think any problems, Mr. Packard. It would be an engineering problem but not a technology issue.

Mr. PACKARD. Thank you, Mr. Chairman.

Mr. BROWN. Thank you, Mr. Packard.

Thank you very much, Dr. Colladay and Ms. Couch. We very much appreciate your testimony.

Dr. COLLADAY. Thank you.

Mr. BROWN. We are now moving to witnesses from the industry. We have Mr. Roger Schaufele and Mr. Marc Constantine.

Would you gentlemen object to coming up together? Do you get along with each other all right? And we will ask you each to present your testimony, and then we will question you together and try to save a little time in doing so.

Do you want to proceed first, Mr. Schaufele?

Mr. SCHAUFELE. Yes, sir.

STATEMENT OF ROGER D. SCHAUFELE, VICE PRESIDENT, ENGINEERING, DOUGLAS AIRCRAFT CO., McDONNELL DOUGLAS CORP., ST. LOUIS, MO

Mr. SCHAUFELE. Mr. Chairman, it is a great honor to be asked to come here and testify for this subcommittee. In the interest of time, I will ask that my formal remarks be read into the record, I would just like to present a very short summary of those remarks to you.

Mr. BROWN. Fine. They will appear in full in the record.

Mr. SCHAUFELE. No. 1, as a member of the technical community, I am really very much struck by the fact that the technical views presented here this morning by previous witnesses, Dr. Keyworth, Dr. Cooper from DARPA, Mr. Williams and Dr. Colladay from NASA, are as similar as they are with regard to the overriding technical issues for this type of vehicle.

As a major developer and supplier of aerospace vehicles, we at McDonnell Douglas agree with the need for a U.S. Government led technology development and validation program and economic evaluation efforts leading to high speed, long range, commercial transports in the 21st century. Until comprehensive design and economic studies can identify the best systems for these transports, such technology efforts should cover flight speeds from mach 2 through mach 5 and beyond.

For the mach 5 transports, where we have concentrated our preliminary studies, the technology needs include hybrid turbo-ramjet engine validation and nacelle airframe aerodynamic integration, application of expert systems for flight management, and validation for application of rapid solidification rate titanium materials. If the United States expects to be in the world lead position in this potentially important transportation segment, a properly structured and pace flight technology and demonstration program is really needed.

Thank you.

[The prepared statement of Mr. Schaufele follows:]

STATEMENT BY

ROGER D. SCHAUFELE

VICE PRESIDENT ENGINEERING

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

BEFORE

COMMITTEE ON SCIENCE AND TECHNOLOGY

SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS

U.S. HOUSE OF REPRESENTATIVES

JULY 24, 1985

Mr. Chairman and members of the Subcommittee, I am Roger D. Schaufele, Vice President, Engineering at Douglas Aircraft Company, a component of the McDonnell Douglas Corporation.

We at McDonnell Douglas appreciate this opportunity to testify on the high speed aeronautical technology needs of the United States for long distance travel in the 21st century. As shown in Figure 1, our 21st century air travel requirements can be related to two of the three National Aeronautical Goals published in March of this year by the Office of Science and Technology Policy (OSTP), Executive Office of the

President. Goal 1—to provide the technology for a new generation of subsonic transports by the 21st century—relates to our continuing needs for efficient air transportation over distances up to transcontinental or trans-Atlantic. Goal 2 specifically aims at efficient trans-Pacific flight to meet needs growing out of our expanding commerce with the Pacific-rim nations; since 1950, our trade with these nations has grown from 7% of our total to over 30% and now exceeds our trade with Europe. Goal 3 relates to travel to and from Earth orbit.

The OSTP assigned first priority to technology development toward Goal 1 (recognizing such technology is fundamental to achievement of all three goals). It also urged concurrent pursuit of those additional technology developments that are specifically relevant to Goals 2 and 3. We agree with the OSTP's goals and technology priorities. However, in keeping with the Subcommittee's purpose to focus this hearing on Goal 2, my comments on technology needs will be confined to specific efforts for the long range, hypersonic transport and will assume that the common technology adaptable from Goal 1 is in hand.

McDonnell Douglas is experienced in the technology needs for high-speed flight. We have produced a greater variety of manned aerospace vehicles capable of supersonic or hypersonic

speeds in the atmosphere than any other corporation in the world. They range from early flight test aircraft like the D-558-I and II, the F5D, and the X-3 (Figure 2), to F-15, F-18, and AV-8B production fighter aircraft and entry vehicles like Mercury, Gemini, the ASSET (Aerothermodynamic/Elastic Structural Environmental Tests) vehicle, and the BGRV (Boost Glide Re-entry Vehicle) of Figure 3. We have also extensively studied, a variety of advanced fighter aircraft capable of hypersonic speed (Figure 4). Moreover, we have recently conducted conceptual studies of system options for a high-speed transport that could efficiently serve the Nation's needs for trans-Pacific travel—the so-called "Orient Express."

ORIENT EXPRESS OPTIONS

The options that have been proposed for an Orient Express range from Mach 2 "supersonic" aircraft to Mach 5 "hypersonic" aircraft. Recent emphasis has been on a kerosene-fueled supersonic transport to operate at Mach 2.7. This vehicle concept is an outgrowth of NASA's Advanced Supersonic Technology (AST) Program of the 1970's. It looks somewhat like the McDonnell Douglas SST concept (Figure 5) which was developed in the AST Program.

However, more recent McDonnell Douglas studies of high speed aircraft concepts for long range air transportation have indicated potential advantage for cryogenic-hydrocarbon-fueled aircraft operating in the Mach 4-5 range. An artist's concept of such a Mach 5 transport is shown in Figure 6 with deployable forward aerodynamic surfaces (canard and vortex generator) and the cockpit exposed for landing.

We recognize that more detailed, comprehensive design studies are needed and that solid economic studies of the transportation system need concentrated effort, but our work so far suggests that we should more aggressively address this potentially beneficial transportation concept. Concurrently, McDonnell Douglas recommends that we step up the gain on technology developments relevant to speeds from Mach 2 to 5. The following comments on technology needs are aimed at the Mach 5 cryogenic-hydrocarbon-fueled transport, where the largest technological challenges exist.

ORIENT EXPRESS TECHNOLOGY NEEDS

Engine technology is pacing for Mach 5 atmospheric flight. While well-developed turbojet and turbofan technologies apply up to Mach 3.5, ramjet technology is needed for higher speeds. Since one must pass through the lower speed range,

efficient Mach 5 flight requires hybrid installations involving the characteristics of both kinds of engines.

In fact, hybrid turbo/ramjets have been studied since 1950 and three prototype hybrid engines have been built and ground tested. An example of such a hybrid engine is the Aerojet Air Turbo Ramjet (ATR) shown in Figure 7. The figure illustrates how the ATR combines characteristics of turbojet, rocket, and ramjet engines.

The technical aspects of the ATR and its potential for enabling higher-speed Orient Express transports will no doubt be included in the Statement to be presented by a representative of the Aerojet General Corporation. Hence, I will only observe that the primary need for further development of hybrid engines is validation through flight test of their readiness for application. A demonstration engine, sized for flight on one side of an F-15 twin-engine fighter aircraft, would adequately demonstrate the critical turbo machinery portion of the hybrid to Mach 2.5.

The other outstanding, engine-related technology development need is efficient aerodynamic integration of the nacelle into the compressive flow field of the airframe. Further development of computational fluid dynamics computer programs is needed along with wind tunnel tests to verify their accuracy.

Ultimately, aerodynamic integration technology for such vehicles will have to be validated by large scale flight tests. No other major aerodynamics technology issues for Mach 5 flight are now apparent.

In cruise flight, the crew of a Mach 5 transport will control the aircraft through an "expert" flight management system that will regulate changes for safe energy management. Thus, continued development of "artificial intelligence" enabling technology for flight at these speeds and flight tests for technology validation of resulting flight management systems will be mandatory.

In cruise, the crew will also rely on sensors and digital cockpit displays for monitoring not only vehicle systems, but the external environment. Only on takeoff and after deceleration for landing will direct visibility through cockpit windows be provided (Figure 6). Thus, sensing of external electromagnetic radiation and systems for conversion of the resulting signals for internal pictorial display of the external environment may require some development for crew (and, perhaps, passenger) use.

Metallic materials adequate to safely cope with the airframe loads and the maximum temperatures imposed by Mach 5 flight (1100°F) are known. At least one such material—Rapid

Solidification Rate (RSR) titanium developed by McDonnell Douglas Research Laboratories is amenable to superplastic forming of efficient airframe structures. Needed are technology validation efforts, including characterization of material properties for certificable designs, scale up and demonstration at large scale of manufacturing processes, and tests of full scale structural components followed, of course, by flight demonstration.

The remaining technology issues that require comment are environmental. Because of its higher cruise altitude, cruise sonic boom pressures generated by a Mach 5 transport will be significantly lower than Concord sonic boom pressures and somewhat lower than those expected from a Mach 2.7 transport. Expected boom pressure differentials (about one pound per square foot) are low enough that overland cruise flight without adverse public response may be feasible. Development of an acceptable test methodology and generation of statistical data on public response to low level sonic booms would be a prerequisite for efforts to change current law and authorize such operations.

Airport area noise is, of course, an issue that will require evaluation when engine characteristics are better defined. However, the high thrust of a Mach 5 transport will permit a

relatively steep climb out that should minimize takeoff noise in the near-airport environment.

Finally, passenger environmental control systems will require evaluation and some development of engine bleed or special air intake systems for very high altitude operations. Current research on systems for purifying and recycling a large portion of cabin air should apply.

SUMMARY

In summary, McDonnell Douglas agrees with the need for U.S. Government support of technology development and validation programs and economic evaluation efforts leading to high speed, long range commercial transports in the 21st century. Until comprehensive design and economic studies can identify the best system for these transports, such technology efforts should cover flight speeds from Mach 2 to 5. For Mach 5 transports, technology needs include hybrid turbo/ramjet engine validation and nacelle/airframe aerodynamic integration, application of expert systems for flight management, and validation for application of Rapid Solidification Rate titanium material. If the U.S. expects to be in the world lead position in this potentially important transportation segment, a properly structured and paced flight technology and demonstration program is needed.

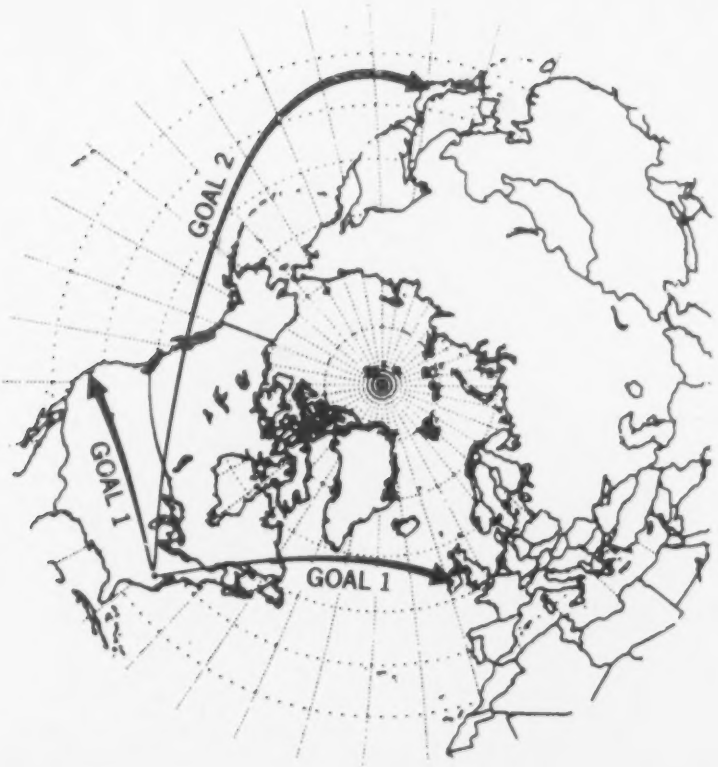


FIGURE 1. NATIONAL AERONAUTICAL R&D GOALS FOR TRANSPORTATION

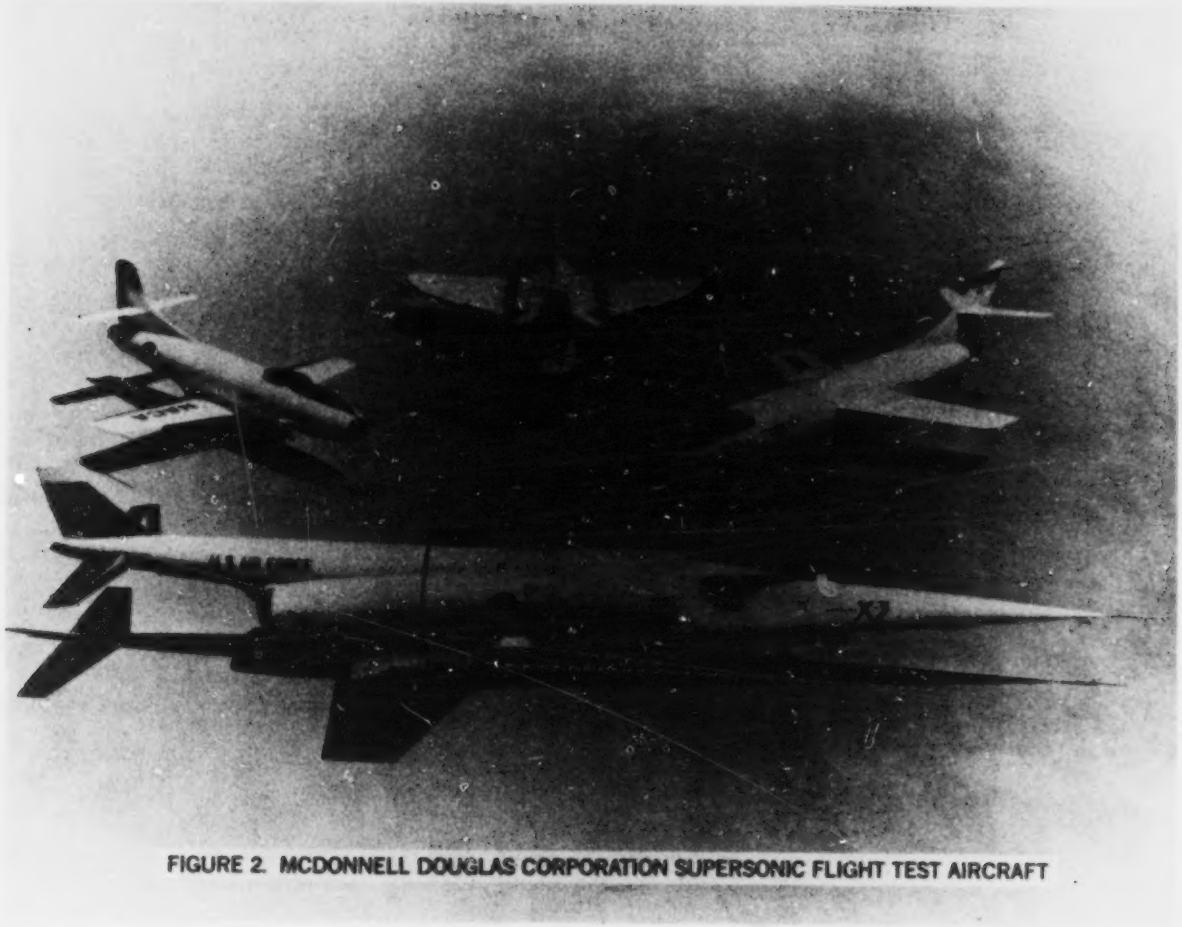


FIGURE 2. MCDONNELL DOUGLAS CORPORATION SUPERSONIC FLIGHT TEST AIRCRAFT

Mr. BROWN. Mr. Constantine, do you want to do as well as Mr. Schaufele?

Mr. CONSTANTINE. I may be a little long winded.

Mr. BROWN. And your statement will appear in full in the record, also.

STATEMENT OF MARC T. CONSTANTINE, VICE PRESIDENT AND GENERAL MANAGER, ADVANCED SYSTEMS DIVISION, AEROJET TECHSYSTEMS CO., SACRAMENTO, CA

Mr. CONSTANTINE. We are pleased to present the following testimony on propulsion technology related to the achievement of sustained hypersonic and transatmospheric flight. Specifically, my testimony will focus on the airturboramjet engine system technology which we believe is the enabling propulsion technology to provide the required self-acceleration from takeoff, the high specific impulse for minimization of fuel consumption, and performance over the required vehicle operating speed and atmospheric envelop.

As shown in our first viewgraph, the Aerojet TechSystems Co., located in Sacramento, CA, is one of seven operating companies of the Aerojet General Corp. which has been a leader in the research, development, and production of high performance, high quality propulsion systems for over 40 years. We have over 12,000 acres of facilities in our Sacramento complex dedicated to that objective.

This next Vu-Graph just shows a portion of those facilities.

We, at Aerojet, invented the airturboramjet over two decades ago. During that period, the initial period, we successfully designed, built, and tested a 26-inch diameter ATR with a sea level static thrust of over 3,500 pounds operating on an ethylene oxide fuel. The next viewgraph shows a picture of that engine operating. That is 20 years ago.

With the termination of the U.S. involvement in the supersonic transport, however, we temporarily redirected our research and development on the ATR until approximately 1982.

The ATR, as you have heard before, is a combined cycle air breathing engine which we commonly refer to as cold turbine technology. By combining the rocket engine and air breathing engine technologies, the ATR can achieve static thrust to weight capability in excess of that available from our most advanced turbojet and turbofan engines. The ATR continues to produce thrust as mach number increases which enables acceleration to more optimal, that is, less drag, higher speed, cruise altitudes of 90,000 to 120,000 feet at mach 5.

As shown in the next viewgraph which you have seen before except the difference here—it doesn't even have an Aerojet logo—but at its core is a rocket jet engine-type cold turbine which performs at a constant, relatively cool temperature of about 1,800 degrees Fahrenheit regardless of aircraft speed or altitude, unlike other concepts which require expensive and exotic materials for even low mach number supersonic propulsion.

The ATR is a unique combination of traditional turbine engine technology blended with off the shelf rocket engine technology. It performs like a turbojet at subsonic speeds and like a ramjet at supersonic speeds. The ATR, we feel, is capable of propelling commer-

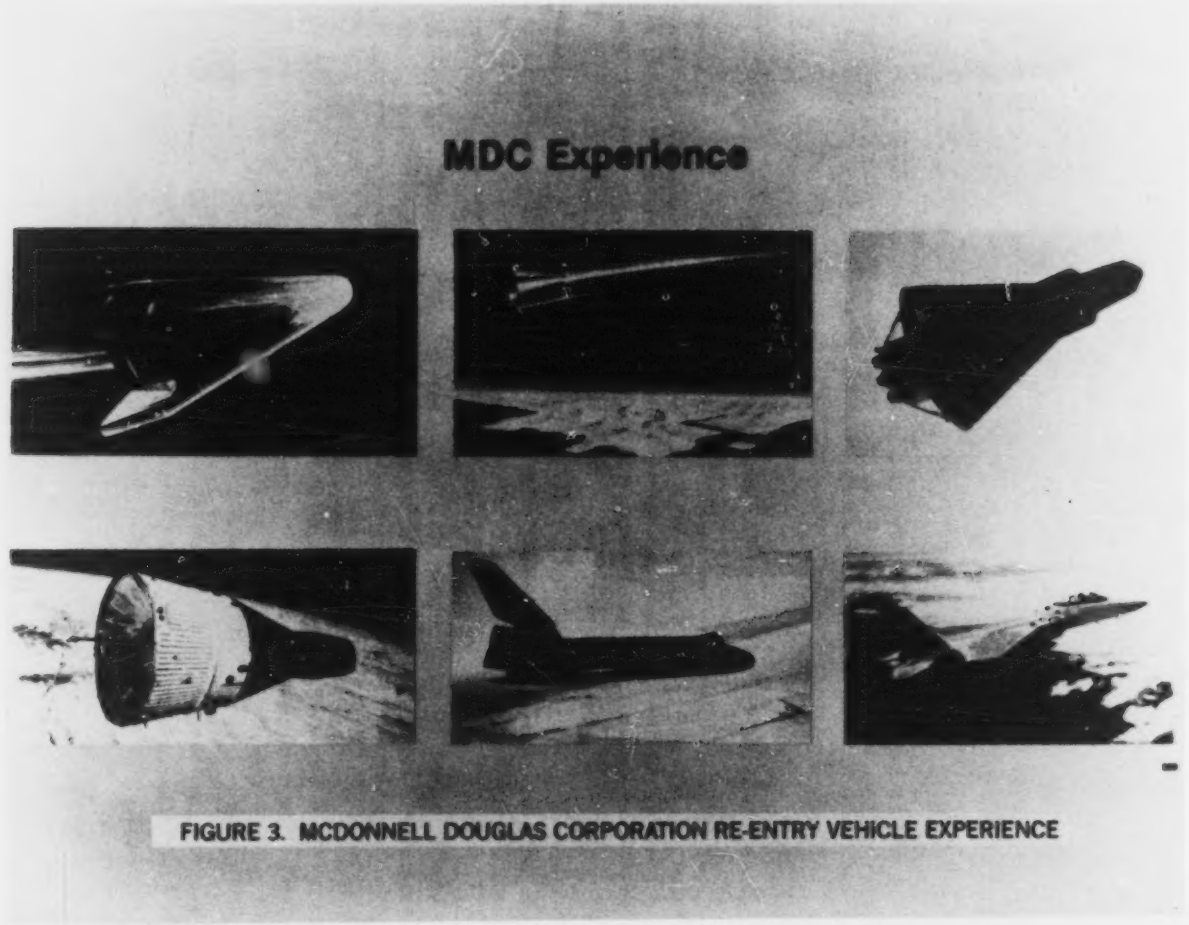


FIGURE 3. MCDONNELL DOUGLAS CORPORATION RE-ENTRY VEHICLE EXPERIENCE

1985 - 1990

MACH 4.5 AIRCRAFT

KEROSENE FUEL, TURBORAMJET ENGINES

FIGURE 4. MCDONNELL DOUGLAS CORPORATION ADVANCED FIGHTER AIRCRAFT CONCEPTS

FIGURE 5. MCDONNELL DOUGLAS CORPORATION MACH 2.2 SUPERSONIC TRANSPORT CONCEPT

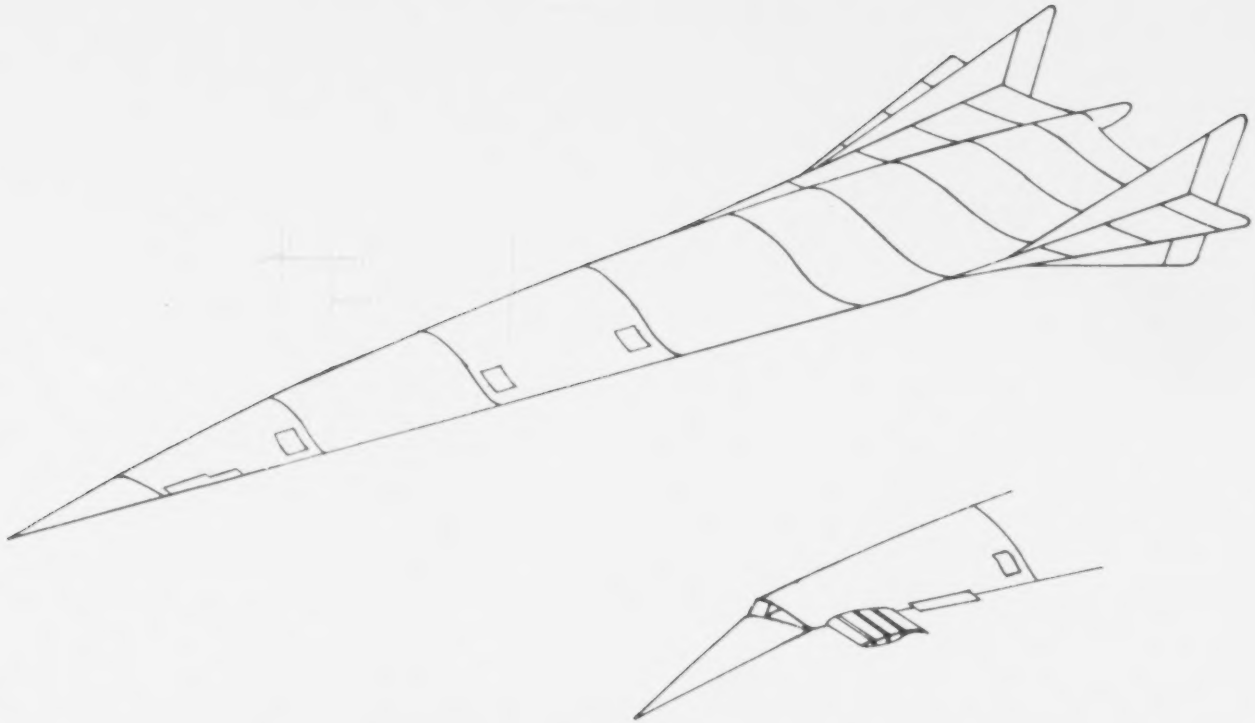


FIGURE 6. MCDONNELL DOUGLAS CORPORATION MACH 5 HYPERSONIC TRANSPORT CONCEPT

AEROJET TechSystems COMPANY

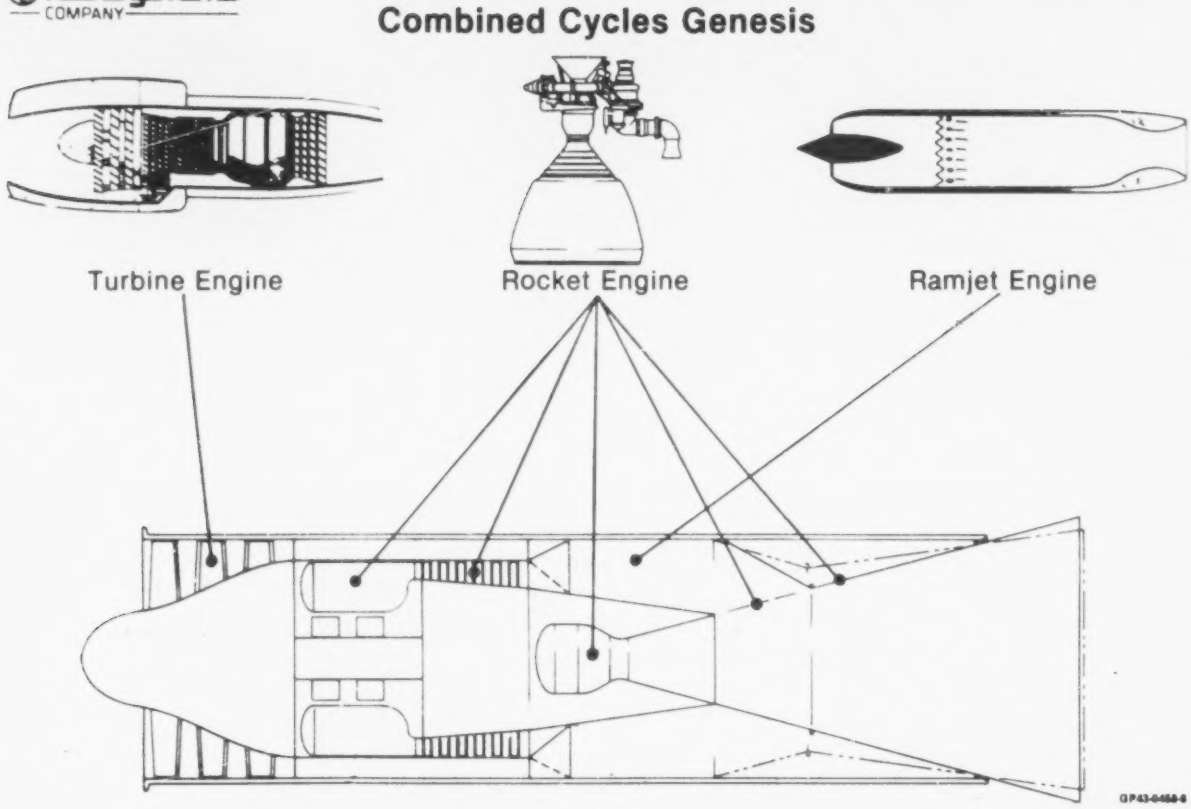


FIGURE 7. AEROJET AIR TURBO RAMJET ENGINE CONCEPT

cial transport aircraft to speeds in excess of five times the speed of sound at altitudes of 100,000 feet or more.

Because we have integrated what we consider contemporary components and subsystems that have an established performance record in similar sized engines into our original design, the ATR is a high performance air breathing engine with what we consider to be low development risk.

Our engine runs on many fuels, can run on many fuels. We have looked at optimization and believe it would run very well on a clean burning and abundantly available fuel such as natural gas, or methane, or hydrogen. This significantly reduces the demands, as you know, on our perishable reserves of crude oil while eliminating the threat of emissions pollution in the upper atmosphere.

As you have heard from the previous testimonies, range factor efficiencies for a hypersonic transatmospheric transport are increased significantly at the more optimal, that is, altitude and speed, cruise conditions attainable with the ATR.

As shown in the next viewgraph, Aerojet has demonstrated the potential of the ATR propulsion system in both 15-inch and 26-inch engine sizes at sea level static conditions with various fuels. The success of our ground test program now requires testing at simulated altitude and mach number conditions. With our development background, we feel we are in a uniquely experienced position to tell you the ATR propulsion system can be fully developed for a flight demonstration program in about 4 years which goes along with what you have heard in previous testimony.

The DARPA/NASA technology demonstration program which have heard about previously which is planned for initiation in fiscal year 1986 will verify the predicted performance in both a subscale and eventually a full-scale flight weight configuration from sea level through altitude and mach numbers applicable to the projected vehicle flight regimes, or applicable to the so-called Orient Express flight regimes. A comprehensive program to demonstrate all elements of the required engine technology has been defined with follow-on work necessary for flight weight validation identified.

We urge this committee to support this all-important program.

I think in order to capitalize on today's opportunities, we must recognize that we are now at a crossroads. The same technological opportunities that we see, as you have heard, are available to the foreign aeronautics community. We must not underestimate the depth of their resolve nor the magnitude of international preeminence aeronautical technology holds, both in the commercial and military sectors.

The objective of our military aerospace plane program to achieve single stage to orbit capability has many technology synergisms with the commercial Orient Express Program with its emphasis on rapid, safe, and cost effective commercial transportation capability. The potential for growth of the ATR through additional combined cycles offers a means to achieve orbit insertion speeds and altitudes. An example of the evolution of the ATR into an ATR rocket cycle is shown in the viewgraph and would permit insertion into orbit.

We agree with others who have suggested it is not so much a question of whether these advances in aeronautics will be made but rather when and by whom. The benefits are too valuable to remain untapped by our ourselves, by our foreign competitors, and by our adversaries. We ask for the support of the ATR technology demonstration program so that our goals will result in the highest possible payoff for the future of the U.S. aeronautics technology.

America's future in aeronautics demands much more than a business as usual attitude. I think we in the U.S. industry as well as the Government must work together as never before to increase accomplishment, enhance affordability, and maintain our country's technological lead in aeronautics.

As I stated previously and you have heard from others, we see propulsion as the enabling technology and we at Aerojet, for one, are committed to development of propulsion systems such as the ATR for the future commercial and military program requirements.

Mr. Chairman, we are providing the written testimony which does include additional technical details and applicable experience for the record of your hearing. I will conclude by expressing my sincere appreciation, on behalf of myself and the Aerojet TechSystems Co., for this opportunity to appear before your committee on what I consider to be a very significant and exciting issue.

Thank you.

[The prepared statement of Mr. Constantine follows:]

STATEMENT

OF

Mr. Marc T. Constantine
Vice President and General Manager,
Advanced Systems Division

AEROJET TECHSYSTEMS COMPANY

before the

Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology
House of Representatives

24 July 1985

Mr. Chairman, Congressional Members, and Staff of the Transportation, Aviation, and Materials Subcommittee.

I am Marc Constantine, Vice President and General Manager of the Advanced Systems Division of the Aerojet TechSystems Company. We are pleased to present the following testimony on propulsion technology related to the achievement of sustained hypersonic and transatmospheric flight. Specifically, my testimony will focus on the Air Turbo Ramjet (ATR) engine system technology which we believe is the enabling propulsion technology to provide the required self acceleration from takeoff, the high specific impulse for minimization of fuel consumption, and performance over the required vehicle operating speed and atmospheric envelope.

The Aerojet TechSystems Company, located in Sacramento, California is one of the seven operating companies (Figure 1) of the Aerojet General Corporation, which has been a leader in the research, development and production of propulsion systems for over 40 years. We have over 12,000 acres of facilities in our Sacramento complex (Figure 2) dedicated to that objective.

We at Aerojet invented the Air Turbo Ramjet two decades ago. During that period we successfully designed, built and tested a 26" diameter ATR with a sea level static thrust of over 3,500 lbs. operating on ethylene oxide fuel (Figure 3). However, with the termination of the U.S. involvement in the supersonic transport, we temporarily redirected our research and development on the ATR until 1982.

The ATR is a combined cycle air-breathing engine (Figure 4) which we commonly refer to as "cold turbine" technology. By combining the rocket engine and air-breathing engine technologies, the ATR can achieve static thrust to weight capability in excess of that available from our most advanced turbojet and turbofan engines. The ATR continues to produce thrust as Mach number increases which enables acceleration to more optimal, (i.e., less drag, higher speed) cruise altitudes of 90,000-120,000 feet at Mach 5.

At its core is a rocket engine type "cold" turbine which performs at a constant, cool temperature regardless of aircraft speed or altitude, unlike other concepts which require expensive and exotic materials for even low Mach number supersonic propulsion.

The ATR is a unique combination of traditional turbine engine technology, blended with off-the-shelf rocket engine technology. It performs like a turbojet at subsonic speeds and like a ramjet at supersonic speeds. The ATR is capable of propelling commercial transport aircraft to speeds in excess of five times the speed of sound at altitudes of 100,000 feet or more.

Because we have integrated contemporary components and subsystems that have an established performance record in similar size engine configurations into our original design, the ATR is a high performance air-breathing engine with low development risk.

Our engine runs on clean-burning (non-polluting) and abundantly available natural gas (methane) or hydrogen. This significantly reduces the demands on our perishable reserves of crude oil while eliminating the threat of emissions pollution in the upper atmosphere.

As you have heard from the previous testimonies, range factor efficiencies for a hypersonic transatmospheric transport are increased significantly at the more optimal (i.e., altitude and speed) cruise conditions attainable with the ATR.

Aerojet has demonstrated the potential of the ATR propulsion system in 15" and 26" engine sizes (Figure 5) at sea level static conditions with various fuels. The outstanding success of our ground test program now requires testing in simulated altitude and Mach number conditions. With our development background, we are in a uniquely experienced position to tell you the ATR propulsion system can be fully developed for a flight demonstration program within four years.

The DARPA/NASA-Lewis Research Center ATR technology demonstration program planned for initiation in FY 86, will verify the predicted performance in both a sub-scale and full-scale flight weight configuration from sea level through altitude and Mach numbers applicable to the projected "Orient Express" flight regimes. A comprehensive program to demonstrate all elements of the required

AEROJET GENERAL
A GenCorp COMPANY

Aerojet Operating Companies

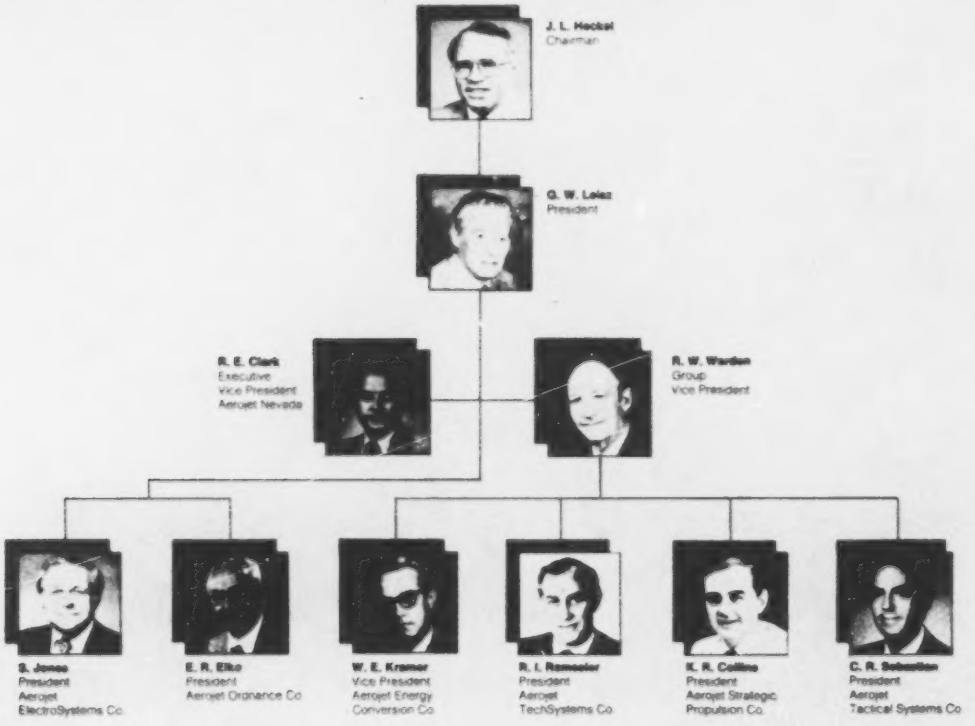


Figure 1

TechSystems

Manufacturing, Engineering And Administration Area

Figure 2

AEROJET TechSystems COMPANY

ATR Engine Cycle Test

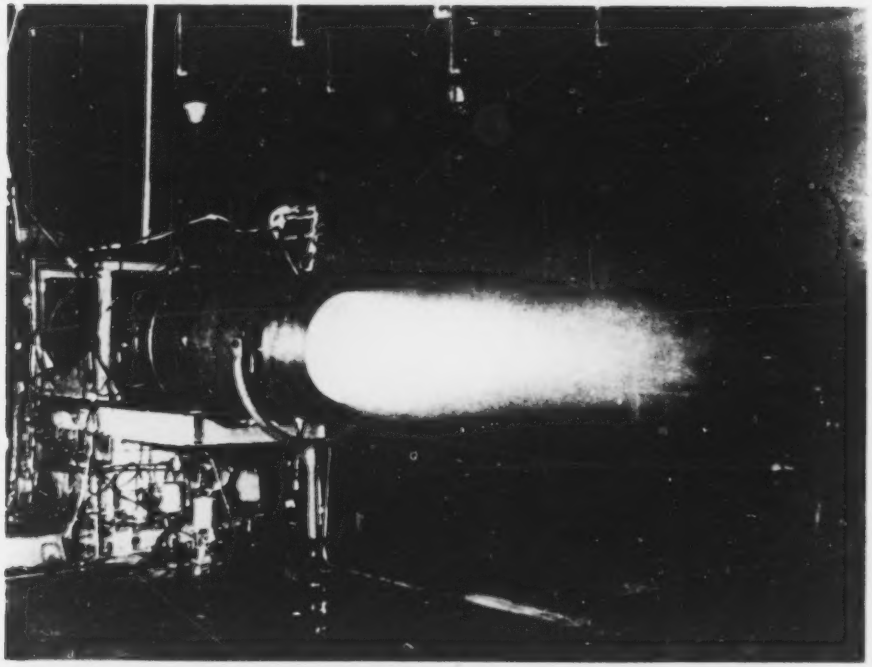
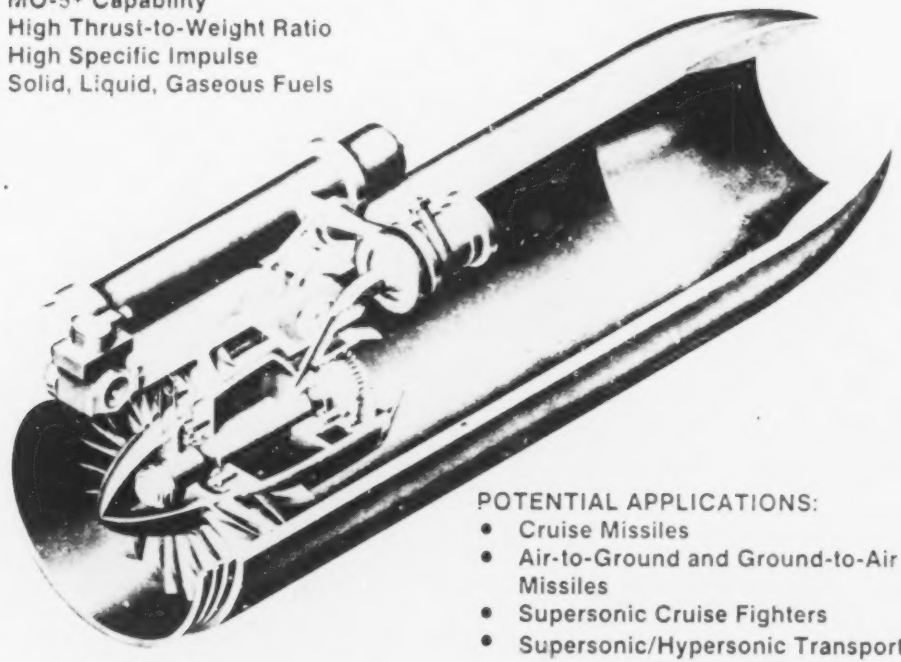


Figure 3.

AEROJET TechSystems COMPANY

Air Turboramjet (ATR)

- MO-5+ Capability
- High Thrust-to-Weight Ratio
- High Specific Impulse
- Solid, Liquid, Gaseous Fuels



POTENTIAL APPLICATIONS:

- Cruise Missiles
- Air-to-Ground and Ground-to-Air Missiles
- Supersonic Cruise Fighters
- Supersonic/Hypersonic Transports

Figure 4.

engine technology has been defined with follow-on work necessary for flightweight validation identified.

We urge this committee to support this all-important program.

In order to capitalize on today's opportunities, we must recognize we are now at a crossroads. The same technological opportunities that we see, are available to the foreign aeronautics community. We must not underestimate the depth of their resolve nor the magnitude of international preeminence aeronautical technology holds, both in commercial and military sectors.

The objective of our military aerospace plane program to achieve single stage-to-orbit capability has many technology synergisms with the commercial "Orient Express" program with its emphasis on rapid, safe and cost-effective commercial transportation capability. The potential for growth of the ATR through additional combined cycles (Figure 6) offers the means to achieve orbit insertion speeds and altitudes.

We agree with others who have suggested that it is not so much a question of whether these advances in aeronautics will be made, but rather when and by whom. The benefits are too valuable to remain untapped by our foreign competitors and adversaries. We ask for support of the ATR technology demonstration program so that our goals will result in the highest possible payoff for the future of U.S. aeronautics technology.

America's future in aeronautics demands much more than a "business as usual" attitude. U.S. industrial companies and government agencies must work together as never before to increase accomplishment, enhance affordability, and maintain our country's technological lead in aeronautics.

As I have stated previously, we see propulsion as the enabling technology and Aerojet is committed to development of the ATR for the future commercial and military program requirements.

Mr. Chairman, we are providing the written testimony, which does include additional technical details and applicable experience, for the record of your hearing. If you have no further questions, I will conclude by expressing my sincere appreciation, on behalf of the Aerojet TechSystems Company, for this opportunity to appear before your Committee.

SUPPORTING INFORMATION/DATA

TO

STATEMENT

OF

Mr. Marc T. Constantine
Vice President and General Manager
Advanced Systems Division

AEROJET TECHSYSTEMS COMPANY

before the

Subcommittee on Transportation, Aviation and Materials
Committee on Science and Technology
House of Representatives

July 24, 1985

I. INTRODUCTION AND SUMMARY

There is a need for a manned aircraft propulsion system which operates from takeoff conditions with high thrust/weight characteristics to accelerate the vehicle to hypersonic conditions, and has high specific impulse characteristics to enable the vehicle to achieve long range. We are pleased to offer our capabilities to demonstrate a propulsion system which has these characteristics-the Air TurboRamjet (ATR).

The Air TurboRamjet engine, a high performance, combined cycle engine, operates like a turbojet at subsonic speeds, and like a fan-boosted ramjet engine at supersonic and hypersonic speeds. The ability of the ATR to operate from subsonic to hypersonic speed with the same engine has significant size, weight, complexity, cost and performance advantages over the costly and complex technologies with which it competes.

Aerojet has unique capabilities to offer in the Air TurboRamjet Demonstrator Engine Program. We have designed, built and tested two successful ATR demonstrator engines. We have expended significant Aerojet funds for the past four years in maturing the ATR technology for high speed, high altitude applications. Aerojet now looks forward to applying its years of technical experience and extensive cycle base to perform the Air TurboRamjet Demonstrator Engine Program.

II. APPLICABLE EXPERIENCE

Aerojet TechSystems Company is a leader in innovative propulsion technology.

Over the past 40 years, since its founding by Dr. Theodore von Karman, Aerojet has been committed to innovation and development in propulsion system technology, as shown by the pioneering technologies shown in Figure 2-1.

Aerojet is also a world leader in manned aerospace propulsion, as evidenced by the propulsion systems used in the following manned aerospace systems:

- Gemini Program (10 Flights) - Titan II
- Apollo Program (10 Flights)
  - Service Propulsion Systems (Command Service Module)
- Skylab Program (3 Flights)
  - Service Propulsion System (Command Service Module)
- Space Shuttle Program (11 Flights)
  - Orbital Maneuvering Systems (OMS)

Aerojet is experienced in designing, fabricating and testing engines using cryogenic propellants. Aerojet has over 20 years of experience in the area of liquid and gaseous hydrogen propulsion, as shown by the engine and research programs listed in Figure 2-2. This experience is current, and is directly applicable to this program.

Aerojet invented the ATR propulsion system cycle. Disclosure of the ATR cycle was made by Mr. William C. House on behalf of Aerojet-General in 1949, and a formal patent application was made in September, 1950. At this time, the U.S. Patent Office issued a Secrecy Order on

the patent application. That order was subsequently removed, and Patent 3,110,153, entitled "Gas Generator Turbojet Motor," was issued to Mr. House in November, 1963.

In the mid-1950's, the U.S. Air Force issued contracts to Aerojet for ATR application studies. Mission performance analyses were conducted for four aircraft and four missile configurations. Several different engine sizes were evaluated. The mission analyses had the purpose of determining the best operating regime for the engine. These studies verified the superiority of the ATR over the other power plants used for such military missions within the defined regime.

During the course of these studies, engine performance calculations were made. To verify the component performance calculations, a 26-inch diameter demonstration engine was designed, built and tested as shown in Figure 2-3. This engine developed 3750 lbs. thrust at sea level static conditions. Ethylene oxide was used as the primary fuel and was decomposed in gas generators. The secondary fuel (JP-4) was injected directly into the combustion chamber. Approximately 70 tests were conducted under the Air Force contract. These tests confirmed the theoretical design calculations and demonstrated the feasibility of the ATR concept. However, no applications of the type requiring use of the ATR were being developed at the time, and further work on the ATR was suspended.

During the early 1960's, Aerojet conducted application studies for the Supersonic Transport (SST). The fuels studied for these applications were hydrogen and methane to be used with a heat exchanger for fuel vaporization. Because turbojets began to reach the limits of their capability, the ATR cycle began to win acceptance. However, the SST program was stopped by the U.S. Government, and the Aerojet effort was again curtailed.

Recent studies of the ATR propulsion cycle by the Naval Weapons Center revealed the potential of the ATR for providing efficient and

flexible propulsion of target vehicles at low cost. Interest by the Navy encouraged Aerojet to proceed with development of a prototype test-bed ATR engine sized to meet the needs of supersonic-cruise tactical weapons and air targets. This 15-inch diameter engine, shown in Figure 2-4, was designed, built and successfully tested during 1982.

Also in 1982, a contract was awarded to Aerojet by the U.S. Navy for a preliminary design based on the AQM-37 target vehicle airframe with a 12-inch diameter, 1200 lb. thrust ATR propulsion system. The ATR propulsion system allows utilization of relatively benign propellants in place of the hypergolic propellants used in the current version of the AQM-37, and provides increases in vehicle range and Mach number capability. In 1983, an Aerojet funded effort generated a detail design package for a 12-inch diameter flightweight OTTO II/Methanol fueled ATR.

In 1984, Aerojet was awarded a contract to utilize existing Aerojet ATR computer codes to develop a well-documented ATR synthesis and cycle analysis capability to enable the Air Force and system contractors to synthesize and evaluate ATR engine designs for missile applications.

One of the candidate engine designs being characterized in this program is the solid fuel gas generator (SFGG) ATR, which fulfills the need for a low cost air-breathing propulsion system with wide mission flexibility. The SFGG ATR is ideally suited for emerging supersonic standoff missile applications because it enables supersonic speeds at low, medium or high altitudes with extended range capability (greater standoff). This results in greater aircraft survivability, as well as greater missile survivability. In early 1985, Aerojet received a subcontract from Boeing Aerospace to assist in evaluating both solid and liquid fueled ATR engines for Air to Ground Missile (AGM) applications under contract to the Aero Propulsion Laboratory.

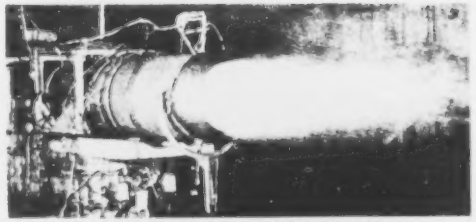
Also in 1985, Aerojet continued its in-house support of ATR technology for the fourth consecutive year. Planned activities include testing of a throttleable solid fuel gas generator ATR demonstrator engine. This will be accomplished by modifying the 15-inch diameter engine which was designed, fabricated and tested in 1982.

AEROJET TechSystems COMPANY

ATR Historical Overview

1955 DEMONSTRATOR ENGINE SUCCESSFULLY BUILT AND TESTED

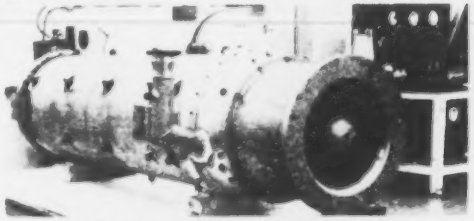
- 26 IN. DIAMETER
- 3750 lbF SLS THRUST
- ETHYLENE OXIDE



1964 APPLICATION STUDIES CONCLUDED THAT COST PER SEAT MILE OF A SUPERSONIC TRANSPORT/LNG-FUELED ATR COULD EQUAL THAT OF SUBSONIC COMMERCIAL JET

1982 DEMONSTRATOR ENGINE SUCCESSFULLY BUILT AND TESTED

- 15 IN. DIAMETER
- 1000 lbF SLS THRUST
- HYDRAZINE



1983 FLIGHTWEIGHT DESIGN OF LOW-COST MISSILE ENGINE VIRTUALLY COMPLETED

- 12 IN. DIAMETER
- 1200 lbF SLS THRUST
- OTTO II/METHANOL FUEL

1984 PERFORMANCE AND SIZING STUDIES PREDICT ATR, ATR/R APPLICABLE TO HYPERSONIC, TRANSATMOSPHERIC VEHICLE MISSIONS

Figure 5.

AEROJET TechSystems COMPANY

ATR growth versions provide additional thrust capability

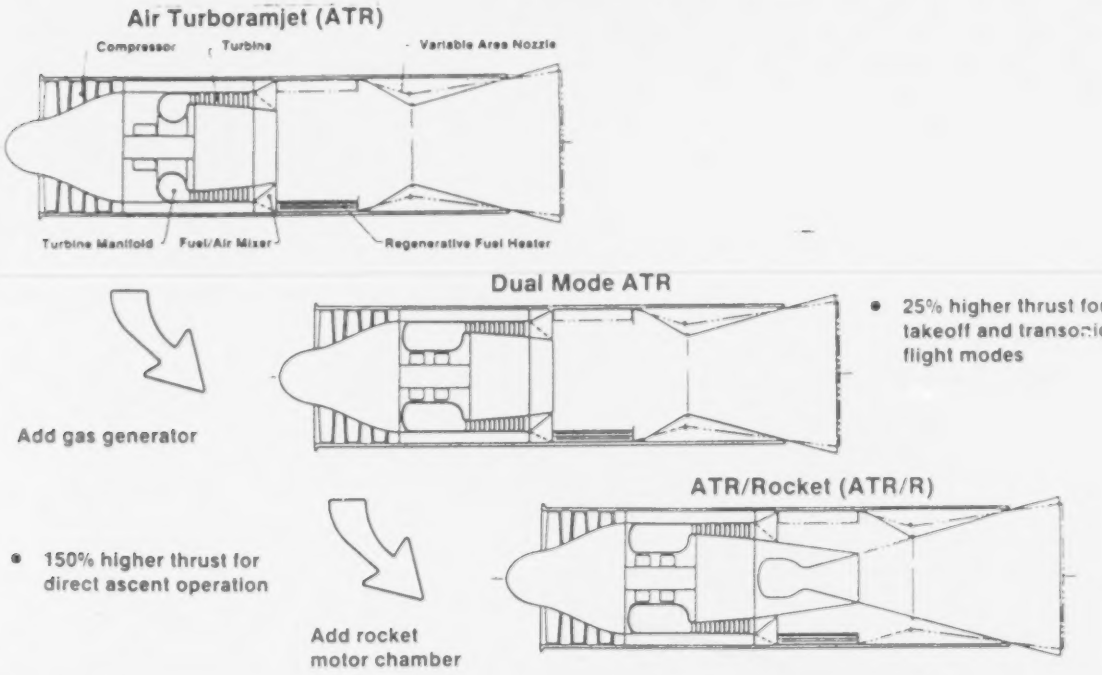


Figure 6.

III. AIR TURBORAMJET DESCRIPTION/OPERATION

A. The Air TurboRamjet Engine Features

The Air TurboRamjet (ATR) is an air-breathing engine cycle which combines the best features of the turbojet engine and the ramjet engine. The ATR performs like a turbojet engine at subsonic speed and out-performs a ramjet at supersonic speeds. The ATR is capable of: 1) producing static thrust greater than an afterburning turbojet, 2) self-accelerating to hypersonic speeds, and 3) operating as a fan-boosted ramjet at supersonic and hypersonic speeds at altitudes over 100,000 ft. The engine is best used for supersonic or hypersonic applications which require a high thrust/weight ratio and a high thrust coefficient.

The ATR, in addition to being capable of operation from Mach 0 to 5, also delivers high performance over this range as measured in terms of thrust to frontal area, thrust to weight, and specific impulse. The ATR thrust per unit frontal area and thrust to weight exceeds that of all air breathing engines, including the afterburning turbojet, as shown in Figure 3-1 and 3-2, respectively. The ATR also has high specific impulse characteristics over the entire flight envelope, as shown in Figure 3-3. The ATR engine operating from Mach 0 to Mach 3 can deliver up to 4000 seconds specific impulse using LH2, and up to 2000 seconds using LOX/LH2. The specific impulse at Mach 5 exceeds 2500 seconds for LH2 and 1500 seconds for LOX/LH2.

The ATR cycle, as shown schematically in Figure 3-4, is a continuous flow air-breathing engine which involves air compression (ram + mechanical), heat addition, and expansion through a thrust nozzle. The unique feature of the engine is that the turbine of the turbocompressor is driven by high pressure/high temperature fuel-rich gas from a gas generator. This fuel rich gas is also the fuel for the engine. The fuel-rich gas may be formed in several different ways:

a) A monopropellant fuel decomposed in a catalytic or thermal bed gas generator,
b) a solid propellant gas generator,
c) a bi-propellant gas generator, and
d) a cryogenic fuel heated and vaporized by heat from the combustion chamber and aeroheated vehicle surfaces.

B. Air TurboRamjet Engine Cycle Description

The ATR employs the same thermodynamic cycle (Brayton) as a conventional turbojet engine, consisting o compression, constant pressure combuston, and expansion to atmosphere. The ATR differs from a turbojet in that the turbine of the turbocompressor is driven by a fuel-rich hot gas from a separate gas generator, rather than by the heated air from a fuel/air gas generator,as in the turbojet.

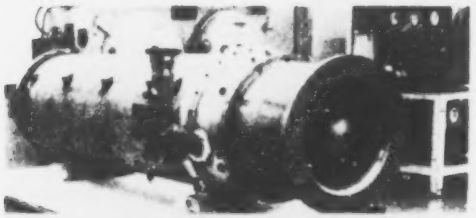
Figure 3-5 compares the typical monopropellant ATR engine cycle to the conventional turbojet cycle operating parameters. Since the turbine stage is not in the airstream, the ATR does not have reduced thrust capability as the Mach number increases. The turbocompressor is much less complex and lighter in weight because of the smaller number of turbine and compressor stages required. An ATR engine is approximately 2/3 the diameter and length, and 1/2 the weight and cost of a turbojet engine of comparable thrust capability.

The ATR thermodynamic cycle as shown in Figure 3-6 illustrates the advantages of an ATR engine compared to a ramjet engine. The compressor increases cycle pressure ratio from the air inlet, resulting in higher thrust and specific impulse values than a ramjet engine. Also, the compressor provides additional pressure to the combustion chamber, resulting in a reduced combustor diameter and a more stable combustion at high altitudes, leading to a higher altitude capability. The hot vaporized fuel also results in more stable combustion compared to the liquid fuel used in a liquid fuel ramjet.

In summary, an ATR can supply high thrust per unit engine area from sea level static to hypersonic flight velocities. It can deliver more thrust per unit engine area and bridges the full operating range of both turbojets and ramjets.

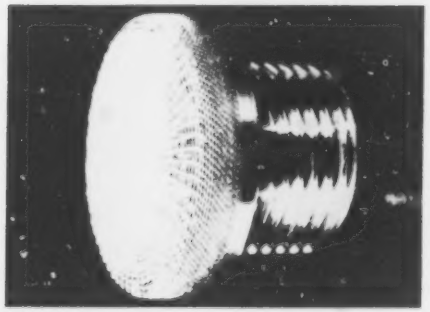
AEROJET TechSystems COMPANY

A COMPANY COMMITTED TO INNOVATIONS IN ADVANCED PROPULSION TECHNOLOGY



ATR

LH_2 TURBOPUMP TECHNOLOGY



PLATELET TECHNOLOGY

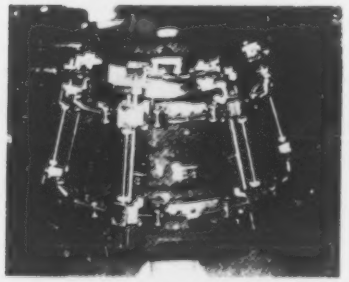


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Figure 2-1

AEROJET TechSystems COMPANY

AEROJET HAS OVER TWO DECADES OF CRYOGENIC HARDWARE DEVELOPMENT EXPERIENCE

Research

Program	Contract	Year	Scope
O_2/H_2 Thrusters, Space Station Aux Prop System	NAS 7-100	1984	Igniter, Thruster Design: 300-500 psi/27-45 lbF Test: 30 psi/2.7 lbF
Low F Isp	NAS 3-22665	1981	Analytical, 100-1000 psi 100-1000 lbF
Plug Cluster Module	NAS 3-20107	1977	1200 Cycles, O/F = 5.5
Comb. Effects	NAS 3-17813	1975	H_2 Film Cooling, O/F = 6-8.0
H_2 Film Cooling	NAS 3-15844	1973	H_2 Film Cooling Experience
Gas/Gas Combustion	NAS 3-14379	1972	GO_2/GH_2 Combustion Experience
H_2 Film/Cond. Cooling	NAS 3-15843	1972	H_2 Film Cooling Experience
Ignition	NAS 3-14348	1971	GO_2/GH_2 Igniters, Spark/Catalytic

Engines

OTV Technology	NAS 3-23170	1982	3K lbF, 2000 psia, Expander Cycle
ETR	NAS 3-16775	1974	LO_2/LH_2 Thruster, 500 psi/1250 lbF
Integrated Thruster Assy	NAS 3-15850	1973	Flightweight GO_2/GH_2, 300 psi/1500 lbF
GO_2/GH_2 Thrusters			
APS, Low Pc	NAS 3-14354	1972	15 psia/1500 lbF
APS, High Pc	NAS 3-14354	1972	300 psi/1500 lbF
O_2/H_2 OMS	NAS 9-8317	1969	500 psi/5000 lbF
M-1	NAS 3-2555	1960	LO_2/LH_2 1,500,000 lbF GG Cycle

Figure 2-2

AEROJET TechSystems COMPANY

AEROJET'S ORIGINAL ATR-DEMONSTRATOR

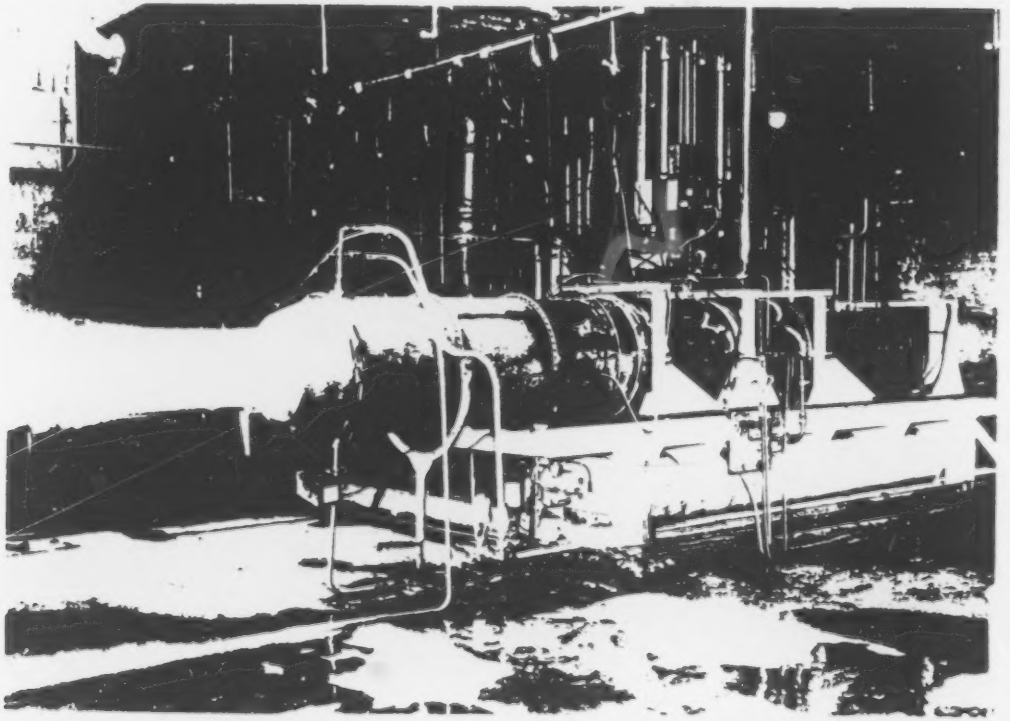

Figure 2-3

15" D ATR DEMONSTRATOR ENGINE

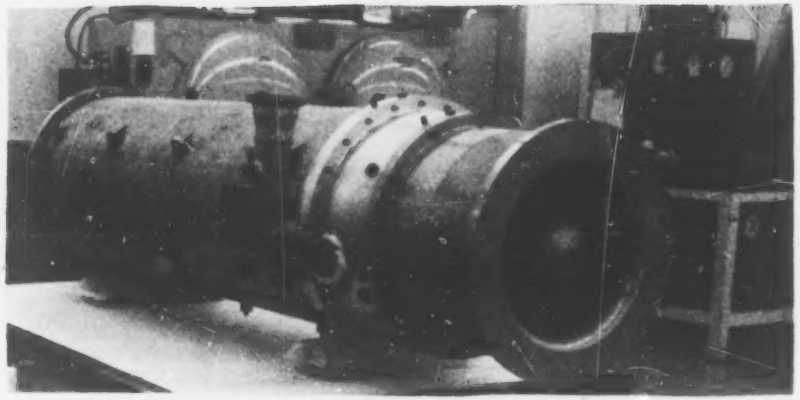

Figure 2-4

TechSystems

ATR has high thrust per unit engine area

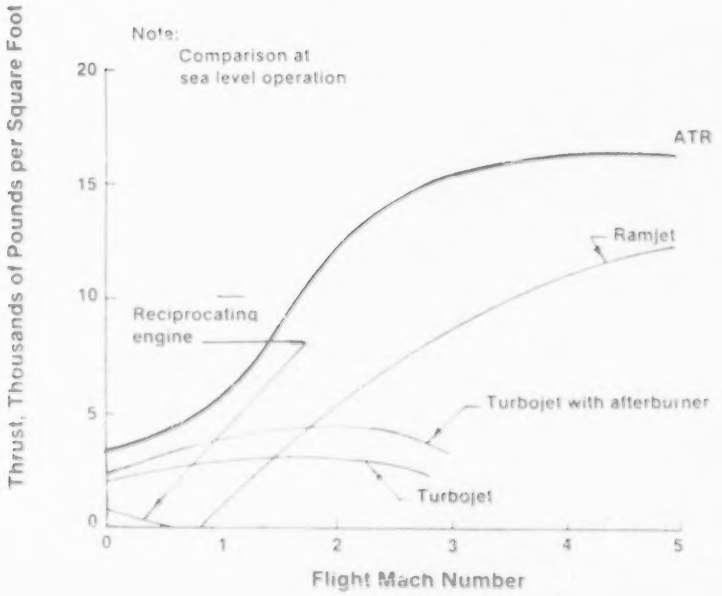

Figure 3-1

Mr. BROWN. Thank you very much, both of you.

Mr. Schaufele, you paid tribute to the technical understanding of the previous governmental witnesses which we always appreciate hearing, but the problems in developing a program like this are both technical, and those are serious enough, and also political and institutional. Fortunately, some of the previous Government witnesses at least had some competence in those fields also.

Tell me how serious you think the threat to our leadership in the domestic civil aviation and aeronautics field is from overseas competitors. How quickly do you perceive that they may be moving and what potential do they have for taking over substantial market shares that the United States now has?

Mr. SCHAUFELE. Mr. Chairman, I think foreign competition is a very serious issue for the U.S. commercial transport manufacturing business. It has been the subject of a number of studies. I think the evidence is very clear that the market share for U.S. aircraft civil manufacturing has continued to shrink in recent years. There is very serious competition from organizations like Airbus Industries in Europe and the Fokker Co. in the Netherlands.

That competition is growing. They are technically capable. They have a lot of very competent engineers who are able to take up the technology and to apply it, and we can only look forward to more and more serious competition in the future.

We know the country of Japan has targeted aerospace as another one of the industries that they wish to become preeminent in, and we can only anticipate that the competition is going to be extremely severe in the future.

Mr. BROWN. What these foreign competitors are doing is exploiting a relatively mature technology and improving on the economics in some ways seeking market niches which we have failed or aren't able to exploit as well as they are. Historically, our lead in this industry has been due to our technological superiority and technological breakthroughs. Is there evidence that the foreign competition is moving in the field of technological innovation in a direction similar to what we have been discussing here so that we could lose even this capability that we have enjoyed in the past?

Mr. SCHAUFELE. I think there is a lot of evidence that they are moving away from their previous mode which you aptly described into one that involves more and more technical innovation, seizing of opportunities, and utilizing the resources that they have to actually overtake American industry.

Mr. BROWN. You see, we have seen this happen in other areas, the automobile industry, the consumer electronic industry, in which, because of our neglect to maintain our innovative capability, our ability to constantly make new technological breakthroughs, we have lost large market shares here, very large market shares in some cases.

The point I am really interested in is are we faced with a similar threat that in effect could lose us an area which we have historically from the development of the aeronautics industry we have had the lead in? I don't want to goad you too much, but I perceive your answer to be that we are in that position where we could lose that.

Mr. SCHAUFELE. Yes, I believe we are and, Mr. Chairman, I would like to add that we have heard a lot today about national

ATR has high thrust-to-weight ratio

Note:
Comparison at
sea level operation

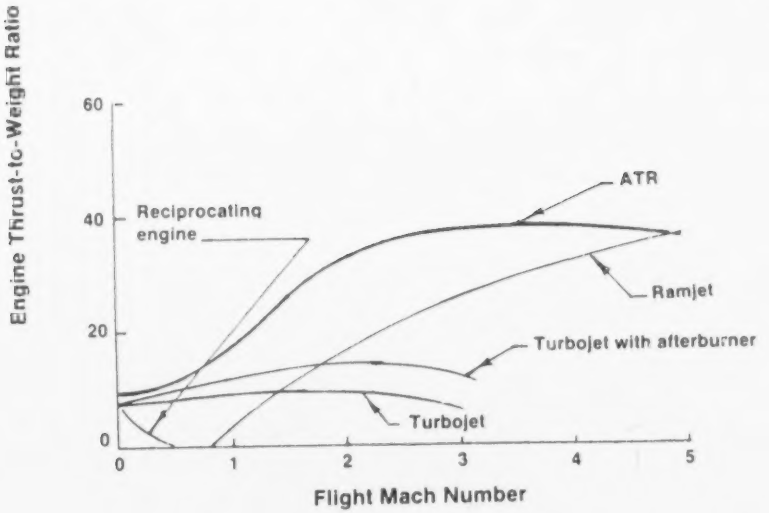

Figure 3-2

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ATR has high fuel specific impulse over entire flight envelope

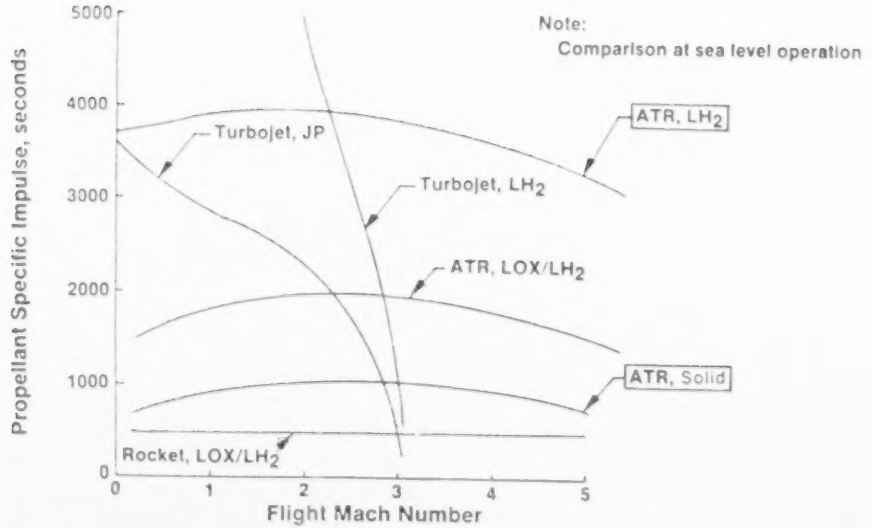

Figure 3-3

AEROJET TechSystems COMPANY

ATR ENGINE SCHEMATIC

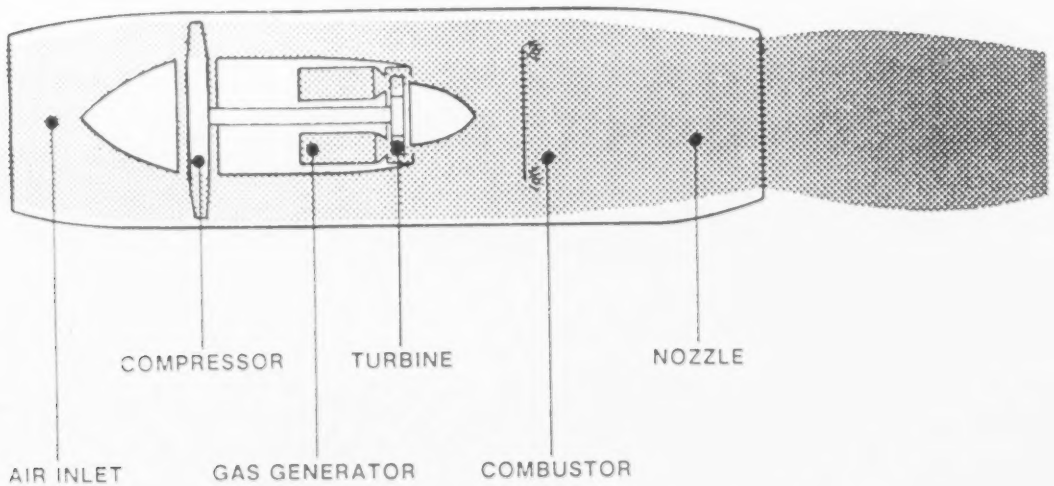

Figure 3-4

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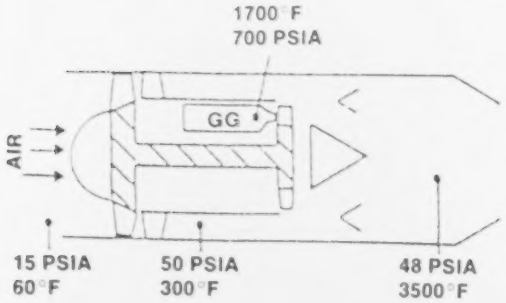
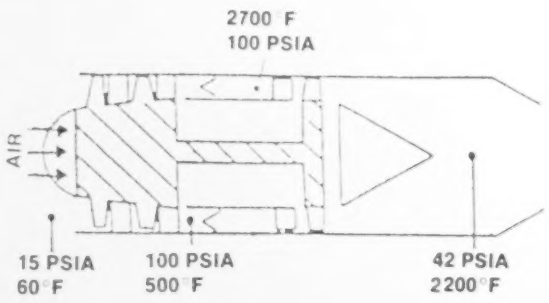
ATR Eliminates Material Limits Of Turbine



ATR CYCLE

- TURBINE GAS TEMPERATURE RESULTS FROM SEPARATE GAS GENERATOR AND IS INDEPENDENT OF AIR TEMPERATURE



TURBOJET CYCLE

- TURBINE GAS TEMPERATURE RESULTS FROM COMBUSTION OF AIR AND FUEL AND IS DEPENDENT ON AIR TEMPERATURE

Figure 3-5

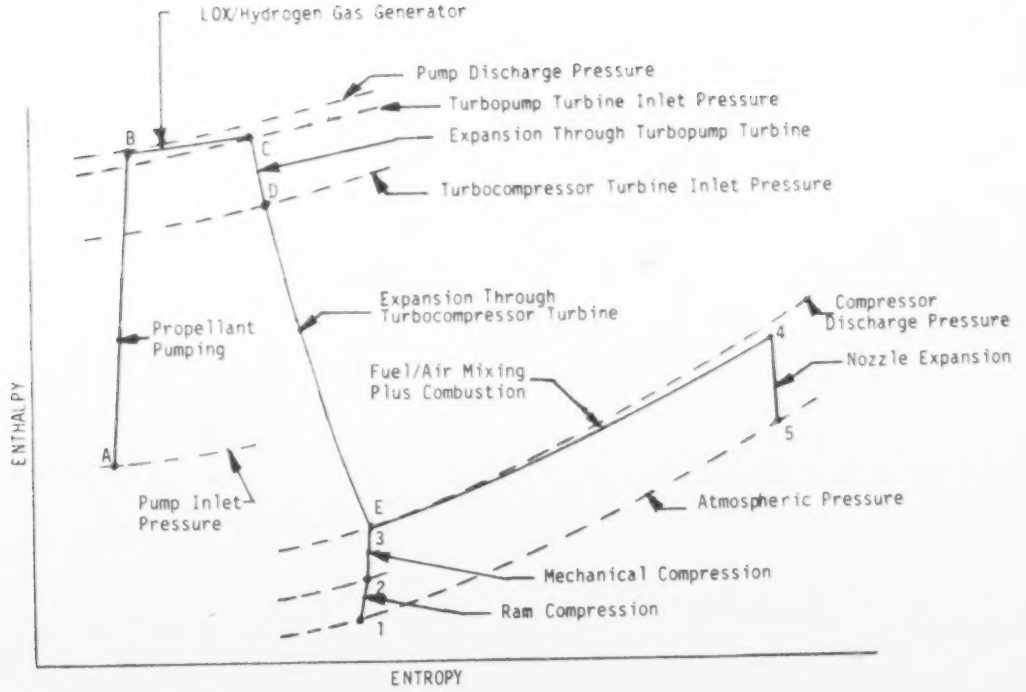


Figure 3-6 LOX/LH_2 ATR THERMODYNAMIC CYCLE

resolve, and I think that is one of the marks of the foreign competition that we notice very much, and that is making the civil aviation industry a national issue and pursuing it with great vigor to the extent that they have.

Mr. BROWN. And they are doing this as a matter of national resolve?

Mr. SCHAUFELE. Yes.

Mr. BROWN. That seems to be the way in which some of our competitors have succeeded in out pacing us in some areas. They have targeted it, they have devoted national resources to it, and they have succeeded in surpassing us in many areas.

Let me ask you this. You have referred to the cooperative relationship between the industry and the Government in this area, the need for Government leadership which has historically marked the aerospace industry because, of course, the Government is a large customer for at least some products, the military aspects of it. Do we need to do anything new here in developing a complex program of the sort we are talking about, one that really does involve major breakthroughs and with applications to both civil aeronautics and space? Do we need to do anything new in an institutional way or do we need to merely continue what we have been doing and doing it a little better maybe?

Mr. SCHAUFELE. I think that the program that we have heard discussed this morning is off to a good start. I, for one, wouldn't recommend any major changes in the way it is being pursued. I think that the cooperation between DARPA and NASA is good. I think the kind of timetables we have talked about, the kind of identification of technical issues is right on target.

I do believe that as the program develops and reaches the stage of commercial application that there may be some significant new approaches that need to be explored in cooperation with industry in order to make certainly a civil transport program become a reality.

Mr. BROWN. Do you have any thoughts on this, Mr. Constantine?

Mr. CONSTANTINE. Mr. Chairman, I think——

Mr. BROWN. I am interested in exploring not only the civil transport thing, but a good deal of the research is coming out of the Federal laboratories. Do we have a problem here in coordinating the Federal laboratory programs at NASA's laboratories and others with the research activities going on in the industry in order to achieve optimum coordination in this area?

Mr. CONSTANTINE. I don't think so, particularly on this program. We have seen a good deal of cooperation between the Government laboratories and also industry. I think one thing that I would say that we might need, and this is a personal feeling, is that we would need a skunkworks type of operation. I don't mean in terms of secrecy as much as I mean in terms of procurement and the ability to react to ideas, react to new advances rapidly and turn them into an end product.

Mr. BROWN. Yes; I see a model of this conceivably in the effort being devoted to the space defense initiative where we have put into one office at a very high level the responsibility for coordinating an extremely complex and expensive program over a number of years. Would you see this as being a—in a sense, it falls at least in

part within the purview of the SDI office as it involves space transportation, but do you feel that a similar effort encompassing the totality of this program including its civil aspects would be useful at some stage?

Mr. CONSTANTINE. Yes; In fact, that creates what I would consider a skunkworks type atmosphere.

Mr. BROWN. Mr. Packard.

Mr. PACKARD. Thank you, Mr. Chairman.

It appears to me that most of our current efforts in civil aviation have been to try to meet the needs of the riding public and filling in the voids, such as commuter needs, more cost effective aircraft, and so forth, to try to fill in the voids of our total fleet of aircraft. I think in the air show this year it became even apparent that we are almost reverting back to old styles of aircraft. One that comes to mind is the F-340, the Fairchild—I don't know who is joint venturing with them now; it has slipped my mind. Anyway, they have gone back to the turboprop, creating aircraft that fill the void of our total fleet needs.

We have not seen any outward appearance of a real thrust forward into future kinds of aircraft, almost a reversal of that. It has been a curious process. Do you see, now, us moving more and more as far as the aircraft construction industry into looking toward the hypersonic type of craft rather than simply filling in with old techniques and old technology our existing fleet?

Mr. SCHAUFELE. We certainly have a fair amount of preliminary study effort going on for advanced transports. We, in McDonnell Douglas, have studied advanced supersonic transport concepts for a number of years.

I think the reason those programs have not going forward has been the real lack of enthusiastic reception in the marketplace.

Mr. PACKARD. Has money been a part of the problem?

Mr. SCHAUFELE. Yes; I do think with the emerging technologies that we heard described today there are great potentials for perhaps new civil transport application, and we certainly will be pursuing those with other members of the Government and the industry with regard to potential applications.

Mr. PACKARD. Except those driven by the need for quieter engines, we have not seen any major new kinds of aircraft come into the marketplace, again filling in the void, and even to the extent of retrofitting 707's and older kinds of aircraft which gives the impression to the American people that really instead of moving forward and using new technology, we are actually retrogressing by simply using old aircraft and trying to make them more compatible in terms of the environment, cost, and so forth.

That brings me to a second question or an extension of that same question into the new technology and these new hypersonic potentials. What are the concerns and what will be the concerns of the industry as it relates to environmental issues that you have to meet and have to address in any aircraft, including the newer ones, such as sonic booms, the noise standards at airports, the air quality standard requirements, all of those? How will that fit into your new concepts?

Mr. SCHAUFELE. We will have to study very carefully the sonic boom issue which we heard described earlier this morning. I think

there is some potential for these hypersonic types of vehicles, because of their extreme altitude and flight regimes, to minimize sonic boom overpressures on land.

I think we also have to be concerned about the airport noise environment, and we do have to be concerned about the quality of the environment within the aircraft itself. I don't really think that the atmospheric pollution issues that were so roundly discussed in the supersonic transport development really are going to present a problem with this type of vehicle.

Mr. PACKARD. One last question for you, Mr. Schaufele. Is McDonnell Douglas involved in the TAV program?

Mr. SCHAUFELE. The corporation has done a number of studies on TAV-type machines, yes.

Mr. PACKARD. You stated in your summary that you agree with the need for the U.S. Government to support technology development and validation. You add to the technology development, you add to that validation and economic evaluation efforts. Would you elaborate briefly on that as it relates to commercial aircraft?

Mr. SCHAUFELE. The emphasis on validation is trying to fill that essential need between the basic research and the application of well understood technology to achieve the low risk that is necessary for entering into a commercial program. I think when we get into that area, it is more of a cooperative venture between Government and industry to make sure that the number of technical unknowns associated with a full-fledged vehicle program are really minimized.

The economics part relates pretty much to the overall need for the vehicle to be reliable in the overall economic environment. It has to provide a needed service. It has to do it at a reasonable fare, and it has to have some potential for return for the manufacturer.

Mr. PACKARD. Have you done any evaluations or analysis of the necessary operating costs that you would have to come under, or has that been done by other agencies?

Mr. SCHAUFELE. To my knowledge, no in-depth studies of that nature have been made. We have been concentrating on the basic technology issues and trying to make sure we have those in hand. Once we come up with what we think is a viable technical concept, then we can go on to do the follow-on studies with regard to the economic viability.

Mr. PACKARD. Thank you.

Mr. Constantine, you have indicated in your testimony that the ATR propulsion system can be fully developed for a flight demonstration program within a 4-year period of time. Are you referring to an experimental aircraft program, or are you referring to a flight test demonstration of an engine?

Mr. CONSTANTINE. What I am really referring to is an experimental aircraft that can go up and that you are confident that when you put the engine on it, it will work when it is on a flight regime. I think Mr. Williams gave indication of a type of program that we think could end up in a flight vehicle perhaps in 4 to 7 years. We concur with this. It all depends on what type of a program you put together and what type of money you spend on it.

Mr. PACKARD. So, the 4 years is the most optimistic of the timetables?

Mr. CONSTANTINE. No; I think actually you might get there a little sooner in terms of getting an engine ready, depending on the amount of funding you put into the program.

Mr. PACKARD. So, funding would accelerate that if it were available?

Mr. CONSTANTINE. That is right. As I had indicated, we see no technological hangup to developing the ATR. I think what we need to do is demonstrate what we have shown at static thrust conditions at simulated mach numbers and altitudes of what we can do, and it will operate.

Mr. PACKARD. What stage are you in right now with that? If someone were to go to your plant to see what was being done, what would be the thing you would show them?

Mr. CONSTANTINE. We have a small demonstrator. It actually is operating on a solid fueled gas generator rather than on a cryogenic or methane or hydrogen, but it is to demonstrate a theory of operation. In addition, of course, we are looking at other applications of such a propulsion system other than just for commercial propulsion.

Mr. PACKARD. Do you perceive your company is in the lead on this particular technology or is there competition coming from other domestic companies or even foreign companies?

Mr. CONSTANTINE. I think there is a lot of competition from domestic and foreign companies, and although, as I say, we invented it over 20 years ago, I think there are any number of propulsion companies that are capable of developing this. We hope we are in the lead, but I wouldn't tell my people that.

Mr. PACKARD. Thank you.

Thank you, Mr. Chairman.

Mr. GLICKMAN [acting chairman]. Thank you.

Mr. Nelson.

Mr. NELSON. Thank you, Mr. Chairman.

Mr. Schaufele, what have your market surveys shown is the potential for a mach 5 vehicle?

Mr. SCHAUFELE. We have done some very preliminary looking at the growth of air transportation throughout the world. I think, as you heard Mr. Brubaker say this morning, one of the fastest growing segments of air travel in the world is the Pacific Rim area. So, looking at the overall long-term growth potential, we are convinced that is an area to really be concerned about.

We haven't done the details of market surveys with regard to what percentage of the travelers there are really going to be attracted to this type of vehicle. We haven't had a vehicle concept long enough to go out and try to put together its economics to try to assess the interaction between the vehicle per se and the ability to attract a market, but that is part of the job that will have to be done.

Mr. NELSON. What is the thinking of your company that it makes sense to move past supersonic and go straight to hypersonic?

Mr. SCHAUFELE. You heard some of those issues discussed earlier. I think, No. 1, the issue is the enhanced productivity that a higher speed vehicle would afford. You have heard the long times involved even flying supersonically over long distances. I think one of the keys to economic viability is the productivity of the vehicle, and

certainly moving into the hypersonic speed range emphasizes that point.

Second, we heard how the sonic boom over land problem is minimized by having vehicles which fly at extremely high altitudes with more blended configurations. That is another area that looks attractive on this type of vehicle.

Mr. NELSON. So, you actually break the sound barrier at a much higher altitude with the hypersonic.

Mr. SCHAUFELE. Well, it has some higher altitude for breaking, but also at sustained cruise and the shock waves which come from the sustained cruise operation are much lesser in their impact on the land and the water below.

Mr. NELSON. Specifically, your company, what are you pursuing on behalf of the military for a transatmospheric vehicle?

Mr. SCHAUFELE. We are looking at number of applications in the transatmospheric vehicle area for the military. I think you heard some of the specific missions described earlier by the gentlemen from DARPA. I think the overall vehicle configurations embody the same concepts as we have talked about here today.

The primary variations are in the propulsion system depending on whether you are looking at a completely within the atmosphere emphasis or whether you are looking at going and returning to orbit. The propulsion systems clearly are different for those particular applications.

We have looked at a number of those for both military and civil applications.

Mr. NELSON. I want to ask both of you gentlemen, Mr. Constantine, you as well, the question about, do you favor a more highly focused national program to flight test the hypersonic concept or do you favor the more broadly based concept as put out by NASA in its November 1984 report? Both of you answer that, please.

Mr. SCHAUFELE. Let me try first. I think we need a combination of both types of programs. I think we need a fairly broad approach in a number of areas such as suggested by NASA, but there are a number of areas where you need to get an extension of the test envelop to higher mach numbers, especially in the propulsion area that requires a test vehicle. And there are a lot of things that need to be done at larger scale in flight which just can't be done in the ground test facility. So, I think you need really both kinds of programs.

Clearly, the rate of progress in this area is going to be enhanced by a flight demonstrator program.

Mr. CONSTANTINE. I think, Mr. Nelson, that I agree. A national program to flight test a hypersonic design would be the best path for rapid progress. NASA has done a very good job of putting together supporting technology, and you can't ignore that.

For example, one of the things that we look at is the materials for light weight, thermal resistance, and high strength. That has to be a part of the supporting technology. Sometimes that gets lost in a focused program. So, we believe it all depends on what you time line is, but if we are looking to a real life vehicle in 7 years, we have to have a focused program, but we can't give up the support which we have done in the past many times and we have found that this has hurt us.

Mr. NELSON. Define what you mean by support when you say don't give up support?

Mr. CONSTANTINE. Well, in the supporting areas of technology, again, as I illustrated through, for example, materials. One of the things that we need for hypersonic flight is an improvement in our materials or improvement in learning how to cool our materials. As you have heard, we have talked about active cooling that is required. This takes some technology that we don't quite have, that we need to study some more. That is what I mean by supporting activities.

Mr. NELSON. Mr. Constantine, on page 5 of your testimony you mention the DARPA/NASA air turbo-ramjet program. Can you describe it for us?

Mr. CONSTANTINE. I think Mr. Williams had described the program in part. What it is, and it is slated to start this fall, is a two-phased program. Phase 1 is to demonstrate a small scale. What I mean by small scale is about a 15-inch diameter, cryofueled, brass board test engine at about mach 5.

In phase 2, then we would expand the technology base at a faster mach 6 plus up larger engine, also cryofueled. This phase would start to establish the real development path for flight weight end item engines.

Mr. NELSON. What do you know of the environmental performance of this ATR?

Mr. CONSTANTINE. We think that the ATR, and you have heard testimony by others on this, is capable of operating over mach zero to about mach 6. I think that is what you mean by environmental.

Mr. NELSON. No—noise pollution.

Mr. CONSTANTINE. Say that again?

Mr. NELSON. Noise pollution.

Mr. CONSTANTINE. Oh, noise pollution. I am not an expert in this field, and I will have to defer to the airplane manufacturer.

Mr. NELSON. OK. Mr. Schaufele.

Mr. SCHAUFELE. We talked a little bit earlier, Mr. Nelson, about some of the environmental issues associated with the airframe and the engine. I think certainly the sonic boom we have heard about is one. We talked a little bit about the overall airport neighborhood noise. We want to make sure that it meets the current and future standards. We talked a little bit about the cabin environmental issues that need to be solved for sustained cruise operation at extremely high altitudes.

I think those are the major environmental issues. I really don't believe that the external environmental issues, such as the pollution of the air by the products of combustion of the propulsion system are really going to be a problem.

Mr. CONSTANTINE. Particularly if we develop this for methane or hydrogen.

Mr. NELSON. Thank you, gentlemen. I appreciate it very much. Thank you, Mr. Chairman.

Mr. GLICKMAN. Thank you, Mr. Nelson. We appreciate your being here and your interest.

Again, I apologize, but we are trying to save the family farmer which is, at this stage, a little higher priority than the one we have right here.

Mr. Schaufele, I am aware that McDonnell Douglas has done some very credible advanced design work on application of these technologies to high speed transport. We have talked about this before. I read your testimony, and while it is interesting, it is not much different from what you have said here before. In fact, I think I recognize some of the same pictures that I have seen before.

I would like to know a little bit about that work, because you are on the firing line and the cutting line and you are doing some of the work now. Mr. Nelson kind of indirectly asked some questions about it in terms of the military side of the picture, but are you working on some systems that could apply to the specific Rim requirements for instance? I think it is important for the committee to know specifically what you are doing.

Mr. SCHAUFELE. As I mentioned to Mr. Nelson, the corporation is involved in preliminary design studies on transatmospheric vehicles of various types for various applications. For the commercial transport application, we really have concentrated the study effort on the mach 5 configuration which is highlighted in the submitted written testimony. That really, in our estimation, is the most viable vehicle at the moment to meet the requirements for civil transport to the Pacific Rim area.

Mr. GLICKMAN. Now, to meet those requirements, to move ahead with that mach 5 vehicle, what specifically do you at McDonnell Douglas, believe the Government should be doing, the defense and the civilian sector of the Government, to promote this effort?

Mr. SCHAUFELE. We highlighted that a little bit earlier, but to recap, we think the Government really needs to support the development of the advanced engines which are really required to enable that type of a program to go ahead. We also need to get technology attention on the engine/airframe integration problems. We need to push ahead on the materials technology that are associated with the very high temperatures and the very lightweight structures required to make such a vehicle possible. And we need to do continued work on the avionics systems which will provide for the guidance control and navigation capabilities of such an advanced transport configuration.

Mr. GLICKMAN. Now, to do all those things, you could argue those are small scope or big scope items. I am presuming that you are talking about a major commitment by the Government.

Mr. SCHAUFELE. It would require a major commitment to get all of those things brought to a state of readiness even to do the flight research vehicle which has been discussed here earlier.

Mr. GLICKMAN. Are you comfortable with what is happening now in the Government sector in terms of NASA and DOD's role in all this? These are your customers, too, but at the same time, I am curious to know whether you think that this Congress ought to focus the effort more carefully or increase the Federal effort.

Mr. SCHAUFELE. I think we are pretty much in agreement with the comments made this morning by Dr. Cooper and Dr. Colladay from DARPA and NASA with regard to the fundamental technical issues, timetable, and the amount of funding required. I think the amount of funding has to be significantly increased over what has been the funding pace, certainly in recent years, in order to get the

technology developed, validated, and prepare us to take the leadership in this important area.

Mr. GLICKMAN. Given the fiscal realities that we are currently operating in, let's assume for the moment that we will not be able to come up with any significant augmentation of either NASA or the Department of Defense in this area, not without overwhelming public support which I don't gauge is out there right now. What does that do to the program?

Mr. SCHAUFELE. It makes it a very difficult program to pursue. It makes for some very difficult choices which I am really not prepared to speak to at this hearing.

Mr. GLICKMAN. When you say difficult choices, what kind of choices are we talking about?

Mr. SCHAUFELE. Choices in terms of priorities for funding.

Mr. GLICKMAN. Would your company have the capability and the resources to do it all?

Mr. SCHAUFELE. I don't think any one company in our industry has the resources to do everything required for such a program. I think it takes a cooperative effort. It is a long-term activity. I think it is the kind of effort that requires the best joint efforts of Government and industry to accomplish.

Mr. GLICKMAN. You see, I would like to see this go, because I think, as I said briefly before, this is the first leapfrogging we have done in aviation in years, significant technological leapfrogging. But I am also a realist and know that it is frustrating to go home and I can't tell my constituents why we can't cut the deficit dramatically. I have a plan to cut the deficit like everybody else does, but none of it, none of it, would entail major new program increases over the next few years. So, we are locked into a problem area.

Now, in my own mind, I am thinking does this mean that this project can't go anywhere, or does it mean that there has to be another source of funding? Does this mean other governments have to come into the picture or foreign companies or international consortia or this kind of thing?

Unfortunately, if we are looking for Uncle Sam to plug in big bucks in the next 3 or 4 years, it just won't happen. The money is just not there, not unless we have a whopping tax increase to pay for it. And I think that as much as my constituents would like to see hypersonic airplanes, they probably would not like to see a whopping tax increase.

So, if you have any suggestions on how to get us out of this mess we are in, please let us know. I think from a conceptual point of view, and I was instrumental in getting the money originally in the NASA budget to get this thing moving, and I would like to get it moving. I also know that spending billions of dollars on the Federal side to move it is going to be very difficult unless, unless the President makes it extraordinarily high priority like he has done with the strategic defense initiative, and he said this is just as important to Star Wars, and those kinds of things happen.

So far, that has not happened. Maybe with Mr. Keyworth's rather generous verbalization of his thoughts, maybe it is going to happen. But without that, I fear that we are just going to be plod-

ding along and moving very incrementally. It is something I would like to see move much faster.

I have no further questions. I want to thank all the witnesses today for coming here for a very enlightening hearing. I can't quite tell you what this committee will do, because I will have to talk with Mr. Brown, the chairman, and others.

From my own perspective, this is not going to drop. We are going to push NASA and its budget next year as they give us the numbers to—and I see Dr. Colladay here—to strongly consider focusing more attention in the area. I don't know about dollars, because dollars are always going to be a problem. And the same thing will be true with the Department of Defense as well.

We would like to have—I think the staff has indicated that you would supply for us for the record the variety of things that you have been doing in connection with your particular projects.

The hearing stands adjourned. Thank you very much.

[Whereupon, at 1:26 p.m., the subcommittee recessed, to reconvene subject to the call of the Chair.]

APPENDIX

Lockheed Advanced Aeronautics Company

A Division of Aeronautical Systems Group
Burbank, California 91520 (805) 257 5760

Ben R. Rich
President

July 24, 1985

Mr. A. Scott Crossfield
2321 Rayburn Bldg.
Washington, D.C.

Dear Scott:

Although I was unable to attend the Congressional hearings on July 24 regarding high speed technology, let me say that I totally agree with the thrust that Congressman Glickman is pursuing. There is no doubt in my mind that the U.S. Government must pioneer this flight regime region as the next logical step in our leadership role in aviation.

I have collected my thoughts on the subject and would like to submit a statement on the part of my company for submittal in the congressional records in support of your activities.

Let me personally extend my appreciation to you as well as Congressman Glickman on your zealous and justifiable pursuit of this critical technology.

Regards,

Ben

Ben R. Rich

STATEMENT OF

LOCKHEED ADVANCED AERONAUTICS COMPANY
SAUGUS, CALIFORNIA

for the

SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS
COMMITTEE ON SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

Lockheed has been observing with keen interest the re-emergence of activity related to high speed atmospheric flight (ie, Aviation Week and Space Technology; April 22, 1985, pg 45). As the company which pioneered operational jet flight in the United States (P-80) and developed the first Mach 2 (F-104) and Mach 3 (SR-71) operational aircraft, we naturally support the desire of expanding flight frontiers. Nearly 20 years experience with the SR-71 fleet have convinced us that technology exists today to design and produce cost effective Mach 4 airplanes. Beyond Mach 4, however, the technology risks escalate abruptly so the question is how far can the technology be pushed. This statement addresses why high speed flight is desirable, what are the barrier technologies, and how can we reduce the risk of developing high speed airplanes.

MISSIONS

Why high speed? For the military the question has an obvious answer. Offensively, speed offers the advantage of surprise and invulnerability. Defensively, speed reduces reaction time. How much is enough depends on the threat. Specific missions include reconnaissance, strategic bombing, interception, and even transportation for truely rapid response situations.

Commercially the need for high speed transport increases as distances extend. Studies have shown that 3 hours is the nominal comfort limit of passengers. To extend beyond the 3 hour limit, services such as meals and entertainment must be provided to distract the passenger. These services cost fixed weight, add crew members, and are expensive in themselves. Over long distances such as the Pacific Basin, the advantage of speed becomes very obvious.

BARRIER TECHNOLOGIES

The advantages of speed are offset by the temperatures generated as a consequence of high speed flight in the atmosphere. This is most pronounced in the propulsion system and the airframe structure. It results in the need for more exotic materials and fuels. It even causes changes in the chemistry of the air through which the airplane flies. Consider the following concerns.

PROPULSION SYSTEM. The single most critical technology for high speed atmospheric flight is the propulsion system. Studies at Lockheed show that the weight of the propulsion system approaches half the empty weight of the airplane for Mach 5 designs using extrapolations of today's technology. Clearly a dramatic breakthrough is required. Scramjet engines offer the promise of that breakthrough. However, scramjets do not become efficient until speed exceeds Mach 6. How do we get to Mach 6? A mix of propulsion cycles is required. The correct combination of turbojet, ramjet, scramjet, or rocket is not obvious though. That needs to be studied in depth then demonstrated in the real flight environment. Of particular concern is the transition to and from the various cycles and the associated propulsion system dynamics.

For more conventional designs the proper blending of inlet, engine, and nozzle are essential to efficient operation. Improvements continue to be made in this area. But there are no ground facilities that are capable of accommodating the total system; that can only be done in the real flight environment.

Relatively conventional jet fuels can be used up to Mach 4. In the range of Mach 4 to 6 cruise, cryogenic methane or liquid natural gas is suitable. Beyond Mach 6 cryogenic hydrogen fuel must be used. The methane offers the advantage of being more dense than hydrogen, therefore methane designs are more compact. However, hydrogen has more heat content for combustion and more heat sink for active cooling concepts.

MATERIALS. The high temperatures associated with high speed atmospheric flight tax materials to their utmost. Better titanium and steel formulas are needed. High temperature composite materials have not lived up to early promises. However, even with dramatic improvements in materials, insulating substances and active cooling will be required at least locally in and around the propulsion system. If the material concerns for the propulsion system can be solved, they can probably be extended to meet the needs of the rest of the airframe. Seals, fluids, and other supporting materials also will require upgrading to support this realm of flight.

STRUCTURE. Structures have and can be designed to survive at high speed. The question is can they be made light enough. New structural concepts continue to evolve. Unanticipated problems usually arise at the interfaces such as the juncture of the cryogenic fuel tank and the wing spars that must go through or around the tank. Large scale structure needs to be fabricated and tested to prove the concepts and the associated manufacturing techniques. Active control techniques applied to the structure offer the potential for significant weight savings but again flight demonstrations are required to prove the concepts in the aerothermoelastic environment.

TECHNOLOGY DEMONSTRATIONS

Lockheed was an active and enthusiastic participant in the National Hypersonic Flight Research Facility (NHFRF) research airplane design in the mid 1970's. It offered the potential for demonstrating the required technologies as an integrated system in the real flight environment. Since that activity was not carried to fruition, the need still exists. The vehicle must carry the complete airbreathing propulsion system and must cruise long enough to achieve a stabilized thermal balance in the structure. A more operationally oriented configuration then NHFRF would yield more useful data to a wider range of disciplines. A minimum design Mach number of 6 is desirable to push the technology adequately.

Supporting demonstrations of small scale models and full scale components in ground facilities are required steps along the way to the development of the research airplane.

SUMMARY

The United States has made no significant effort to extend speed capability for airbreathing flight in the past 25 years. During that period piecemeal advances in technology have offered the potential for such advances. It is time to focus the improvements in a research airplane that should be designed for sustained Mach 6 flight with airbreathing propulsion. Such a demonstration vehicle offers significant potential for resolving major unknowns in the integration of the airbreathing propulsion devices which are the key to successful high speed flight. Historically, it takes 10 years to develop a new propulsion system. Isn't it time we start down that road?

DON FUQUA, Florida, CHAIRMAN

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U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUITE 2321 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515
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July 25, 1985

HAROLD P. HANSON
Executive Director
ROBERT C. KETCHAM
General Counsel
JOYCE GROSS FRITCHLEY
Republican Staff Director

Honorable James Beggs, Administrator
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Mr. Beggs:

Recently, we became aware of a proposed NASA/DARPA joint program to demonstrate the feasibility of hypersonic propulsion for a variety of civil and commercial applications. We all feel the concept envisioned by DARPA is one of the most promising ideas to come along in many years. Accordingly, we strongly urge you to give top priority to NASA's participation in this effort in the FY 87 budget.

As you know, Dr. Jay Keyworth testified at a recent hearing before the Subcommittee on Transportation, Aviation and Materials, saying that this technology represents nothing short of a revolutionary advance for both aeronautics and space. We agree. It is precisely the kind of breakthrough needed to maintain U. S. preeminence in aviation and space. And it is precisely the kind of leading edge technology that NACA/NASA was created to explore.

We are well aware of NASA's long-term, low-level research in hypersonic propulsion, which has made the present optimism possible. Because of this, NASA is uniquely qualified to participate in the next step, a proof-of-concept demonstration. In fact, it may not be possible without NASA's assistance.

For these reasons, we feel NASA should substantially increase its commitment to hypersonic propulsion in the FY 87 budget.

Sincerely,

Don Fuqua
Member of Congress

Manuel Lujan, Jr.
Member of Congress

George E. Brown, Jr.
Member of Congress

Tom Lewis
Member of Congress

Bill Nelson
Member of Congress

Robert S. Walker
Member of Congress

"ORIENT EXPRESS", a definition (footnote p 6)

The "Orient Express", referenced throughout the testimony, is a strawman for advanced aeronautics applications to civilian requirements for international travel. It is a concept to focus those requirements which was invented by ad hoc participants from the several agencies of the Administration, industry, and the Committee.

The Orient Express would utilize much of the emerging technology described by DARPA for the Aerospaceplane. It adds to the justification for the need for the DARPA development and shares in the application of the results. An Orient Express may be:

1. A 3-500 passenger, Mach 5 transport aircraft that would fly from New York to Beijing in about two hours.

2. Powered by an AirTurboRamjet (ATR) engined fueled by cryogenic methane.

3. A concept which responds to rigid requirements for sonic boom limitations with flight over land, atmospheric pollution, and economic acceptability.

ECONOMIC CONSIDERATIONS

Dr. Gus W. Weiss, Jr.

Submission for the record to the Subcommittee on Transportation, Aviation, and Materials, U.S. House of Representatives, Hearing on High Speed Aeronautics, July 24, 1985.

I am grateful to the Committee to be able to make a submission on arrangements for the development and production of a large high speed commercial transport aircraft, informally called the Orient Express. Since the likely design of such an aircraft is very much an open question, many issues remain to be resolved by market and technical study. In particular, these include the cruise Mach number, structure, fleet demand, development and production cost, and the arrangements by which the Orient Express could be developed and produced. Following the technical success of Concorde and then the abortive U.S. SST program, changes in propulsion, materials, and avionics have made a new recounting of the possibilities of high speed commercial flight timely.

Simply for reference, two aircraft could be postulated, one a fairly straightforward Mach 2.7 SST and the other a more demanding Mach 5 craft whose development would require hypersonic propulsion and the structure associated with an intense aerothermal load. Both aircraft would require demonstrators with government research support, but support would be more justified for the Mach 5 airplane because of its demands for new technology. In no event could the government support commercial production as the Orient Express must stand on its own economic merits; in fact, a portion of the demonstrator cost could likely be recouped by royalties from commercial sales or life cycle use.

At Mach 2.7 use could be made of aluminum, of conventional propulsion, and perhaps of the operating and design experience the U.S. has on variable geometry wings. This craft would be cheaper than a hypersonic transport, but it would still have a sonic boom problem, while the Mach 5 airplane could not avail itself of these conventional technologies and would likely have a takeoff noise problem. On the other hand propulsion ideas as those described by DARPA/NASA and Aerojet could well lead to resolution of the pacing technology for the hypersonic propulsion. Only further development work can say, and this is one persuasive reason funding should be supported by the Congress.

Latent demand for Orient Express is another open issue. This can be judged by successive and interactive demand estimates among variables including macroeconomic growth by region, per capita personal income, demography, and the cost per passenger mile likely to be realized by a high speed transport. A Mach 5 aircraft would have more speculative demand equations because of a lack of experience in economic and traffic projection at that

speed, while those at Mach 2.7 have Concorde experience to draw on. Also, the aerodynamic efficiency at hypersonic speed is an unknown at this point and is another reason for a demonstrator aircraft. Taken in the broad quantitative traffic estimates, especially for new flight regimes, are sensitive to assumptions and often prove in considerable error; in addition, once technology has been demonstrated and reasonable cost achieved, demand could easily materialize far in excess of projections.

On issues of design and production, a technology demonstrator sponsored by the government could both produce and prove the required technology, and depending on final selection, the economics in commercial flight that could be expected. Foreign participation in a demonstrator need not be ruled out, but this would require government-to-government agreements; this should not hamper development but would require a slightly more complex management arrangement than sole support to contractors by the U.S.

Because of the large capital cost an international consortium would be a likely way to move Orient Express into production. This is becoming common in commercial aviation, as for instance in the GE/SNECMA CFM 56 and the V 2500 led by Pratt & Whitney. The risk return calculation has provided a stimulus for such ventures, along with the high cost of development. Such a consortium and its underlying financing would pose all manner of commercial and management problems to be solved, but this has all been accomplished in other ventures and should pose no insuperable difficulties. The main point is to fix a design and a technology that yield an economic and safe aircraft for high speed commercial aviation.

NORTHWEST AIRLINES, INC.
MINNEAPOLIS-ST. PAUL INTERNATIONAL AIRPORT
ST. PAUL, MINNESOTA 55111

STEVEN G. ROTHMEIER
PRESIDENT AND
CHIEF EXECUTIVE OFFICER

August 16, 1985

The Honorable George E. Brown, Jr.
Chairman, Subcommittee on Transportation
Aviation and Materials
Science and Technology Committee
U.S. House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

During the recent hearing concerning development of a hypersonic long-range transport, the question of U.S. air carrier support emerged as a vital component of any design program.

For Northwest Airlines an "Orient Express" serving our routes in the important Pacific Basin is an exciting possibility. We have already made known our interest in the development of such an aircraft.

Northwest fully supports the national aeronautics goal for a hypersonic aircraft proposed in April by the Office of Science and Technology Policy--Executive Office of the White House. We look forward to working with you and other members of Congress, relevant agencies of government, and aircraft manufacturers to further the goal of developing a technologically sound and economically feasible hypersonic aircraft.

Sincerely,

Steven G. Rothmeier

rmh

SUPPLEMENT TO THE

STATEMENT BY

ROGER D. SCHAUFELE

VICE PRESIDENT ENGINEERING

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS CORPORATION

BEFORE

COMMITTEE ON SCIENCE AND TECHNOLOGY

SUBCOMMITTEE ON TRANSPORTATION, AVIATION, AND MATERIALS

U.S. HOUSE OF REPRESENTATIVES

JULY 24, 1985

This supplement summarizes McDonnell Douglas Corporation technical results which support the selection of a Mach 5 cryogenic hydrocarbon-fueled configuration for the high-speed, long-range transport of the future—the "Orient Express."

Performance goals and issues which will most significantly affect selection of an optimum vehicle system include operational productivity and efficiency for commercial viability, development cost toward the same end, and environmental impact. To date, studies have been primarily concerned with defining interrelated vehicle characteristics, such as design

speed and altitude, propulsion system and fuel, and vehicle size and weight, which affect these goals and issues. Only technology available now or in the near term has been considered.

The range of 6500 nautical miles selected for these studies is sufficient to link most of the important cities of the world, even when increasing the length of appropriate routes to avoid problem areas such as the USSR. With this range, flights originating from the east coast of the United States can easily reach Tokyo and Beijing, and flights from the west coast can reach Hong Kong and Sidney. A vehicle with this range would also effectively service European nations in travel to South American and Asian business centers.

One question asked toward definition of the best system for the Orient Express was "Is the speed of the Advanced Supersonic Transport (AST) fast enough or would higher speeds be desirable and attainable?" The cruise speed attainable by the next generation transport will be directly related to the propulsion system and fuel used. This is illustrated in Figure 1 which, for high speed vehicles, outlines a corridor on the altitude versus Mach number plot within which the "dynamic pressure" generated by motion through the atmosphere is sufficient for lifting flight, but not so great it will jeopardize the structure. Energy requirements for flight at

a given speed, coupled with oxygen availability and options for oxygen capture and concentration, lead to selection of different fuels and engine cycles for different portions of this corridor. Below Mach 4, traditional hydrocarbon fuels, like JP-4, provide sufficient energy in turbojets at low supersonic speeds and ramjets at higher speeds. At Mach numbers from 4 to almost 8, either cryogenic hydrocarbons or cryogenic hydrogen in ramjets will provide adequate motive power.

Above Mach 8 only hydrogen "scramjets" (with internal supersonic flow) appear potentially practical. But, such Mach numbers lead to skin temperatures that probably violate our limitation to currently available or near term technology, and such speeds are not essential for efficient commercial transportation at ranges up to 6500 Nautical Miles.

Concentrating, then, on the speed range from that of the advanced supersonic transport, Mach 2.2, to hypersonic flight at Mach 8, there are additional limiting boundaries and issues that further restrict desirable operating regions. These, depicted in Figure 2, include a limit on engine inlet duct internal pressure for subsonic combustion that further restricts the upper limit of practical Mach numbers to Mach 6 and a band of dynamic pressures (shown black) that corresponds to efficient cruise for maximum range. Finally, two

issues which will probably have a large impact on the public acceptance of high speed transports—their sonic boom at ground level and their effect on the ozone layer—begin to point us toward the high end of this Mach number range.

As shown in Figure 2, the ground-level sonic boom pressure differential for a Mach 2.2 transport cruising at 65,000 feet altitude is less than two pounds per square foot (psf)—significantly less than the Concorde sonic boom which, at cruise, is 2.5 psf. In comparison, the ground-level sonic boom pressure differential from a Mach 5 transport cruising at almost 100,000 feet altitude would be less than 1.0 psf—low enough so that public acceptance of overland flights might be expected.

The effect of a high altitude airplane on the ozone layer around the earth is of concern to us all. The AST, as previously proposed and as represented in Figure 2, cruises at approximately 65,000 feet, an altitude at which the ozone layer may be vulnerable because of the low quantity there of atomic oxygen which is needed for ozone restoration through ultra-violet-light-driven reactions with diatomic oxygen molecules. The atomic oxygen at cruise altitudes suitable for a Mach 5 hypersonic transport is sufficiently high to assure ozone level restoration and maintenance at a stable level after depletion as a result of fuel burning. In addi-

tion, methane and hydrogen are cleaner burning fuels than the JP-4 proposed for the AST.

Based on these two important factors, a Mach 5 hypersonic transport cruising at 100,000 feet altitude may gain public acceptance more easily than the previously considered AST.

Pictorial representations of the three configurations which have been compared in MDC studies are presented in Figures 3, 4, and 5. All three configurations were designed to carry 305 passengers 6,500 nautical miles. The McDonnell Douglas Corporation (MDC) Mach 2.2 AST, a cooperative effort with NASA, was tested extensively in wind tunnels. The design study and tests resulted in improving the lift to drag ratio (L/D), a measure of the efficiency of the aerodynamic design, from slightly above 7 to almost 10.5, a substantial advancement in the state-of-the-art. The MDC Mach 5 "Orient Express" and the MDC Mach 5.5 hypersonic transport are representative of methane and hydrogen powered hypersonic transport configurations, respectively.

As noted, the AST configuration was tested extensively, and the current comparison utilizes these data. There is also a significant amount of wind tunnel data available for Mach 5 configurations. These data, presented in the right hand plot of Figure 6, provide a credible basis for the Mach 5 values

of L/D used for this study. As the cruise Mach number of the configuration increases, there is usually a decrease in L/D; however, the data presented in the left hand plot of Figure 6 illustrate that this decrease is not apparent below Mach 4.5. This means that the cruise power required for a properly designed Mach 4.5 configuration is not significantly higher than that required for a Mach 2.2 aircraft. An accompanying increase in altitude is necessary to maintain the same dynamic pressure.

As is also illustrated in this figure, the fineness ratio of the configuration significantly affects its aerodynamic efficiency. The longer, slimmer winged configurations have substantially higher L/D's than the blended body configurations. This effect has a direct impact on the fuel selection because the lower the fuel density, the larger the fuel storage area or body size. The immediately apparent advantage of hydrogen as a fuel is overshadowed by the loss in aerodynamic efficiency caused by the large fuel storage volume required. This effect is illustrated in Figure 7 where the curve on the left presents the propulsive efficiencies of JP-4, methane, and hydrogen. Hydrogen is clearly the best fuel; however, when the airframe and propulsion units are integrated with the addition of aerodynamic efficiency (L/D) for a measure of overall efficiency, the advantage of hydrogen fuel disappears. The configuration sketches in Figure 8

are presented to illustrate the relative effect of the larger fuel volume and resulting greater wetted area on the aerodynamic efficiencies and drag coefficients of the vehicles.

The three candidate configurations selected for this study, and illustrated in Figures 3, 4, and 5, were the Mach 2.2 JP-4 fueled AST, the Mach 5 methane fueled ATR powered hypersonic transport discussed in the statement presented on 24 July, and a Mach 5.5 hydrogen fueled ATR powered hypersonic transport. As previously noted, the basic assumptions common to all three configurations were a passenger load of 305 and a design range of 6,500 nautical miles. The weight of each of the airframes is based on the assumption that full use is made of recent advances in rapid solidification rate (RSR) aluminum and titanium wherever possible. The lower stagnation temperatures at Mach 2.2 will allow extensive use of RSR aluminum while RSR titanium will be required for the Mach 5 and Mach 5.5 configurations. Comparison results are summarized in Figure 9.

Scanning the data presented in Figure 9, there are a number of interesting points—not the least of which is the fact that the hypersonic vehicles can make a round trip in a normal eight hour day, allowing the crews to return to their home base. Another significant comparison is the total volume of the aircraft; because of the lower density of hydrogen, the

fuel volume required is almost five times that required for methane or JP-4 fuels. The total volume of the hydrogen powered configuration is, therefore, substantially larger than the volumes of the other two configurations. Since the weight of structure is directly proportional to the weight it must contain, the hydrogen fueled aircraft has a structural density of approximately 55% of the methane configuration; however, because of its greater surface area, the hydrogen aircraft has an empty weight at least 30% more than the other vehicles. This does not count any extra weight fuel to its greater thermal insulation requirements. Since aircraft structural costs are usually directly proportional to weight, the hydrogen fueled vehicle airframe will probably cost at least 30% more than the other two.

Thus, the data resulting from this study indicate that the methane fueled, ATR-powered Mach 5 configuration would be lightest and have the lowest volume of the three configurations, probably would be no more costly to build than the AST configuration, and definitely would be cheaper than the hydrogen-fueled transport.

The hydrogen fueled configuration take-off gross weight (TOGW) is only slightly higher than the methane powered configuration. Comparatively, because of the high fuel density, the JP-4 fueled vehicle TOGW is approximately 40% higher than

that of methane or hydrogen fuel vehicles. However, the take-off power required for the methane and JP-4 powered vehicles is substantially the same because the increased weight is offset by the higher lift coefficient attainable with the lower wing sweep angle. The take-off power required for the hydrogen fueled configuration would be slightly higher than that required for the other two configurations because of the lower take-off lift coefficient attainable with the large diameter blended body.

The operating efficiency of a hypersonic vehicle must be comparable to that achieved by current subsonic transports before the "Orient Express" can be considered a viable future transport. The data presented in Figure 10 illustrates the operational productivity of a number of aircraft operating today including the Concorde and the SR-71. The wind tunnel data obtained for the MDC AST configuration has been extrapolated to reflect the level of performance expected for the Mach 5 methane powered vehicle. This projection indicates that the "Orient Express" would be more productive than current subsonic transports and significantly more productive than the Concorde.

As always, systems of the future are based on extrapolation of the knowledge of today, and achieving the results shown here will depend on achieving validation of the technology

required for the hypersonic transport. Since all of the technology used in this study is available or near term, validation can and should be attempted as soon as possible. A properly structured and paced development and proof testing of the ATR engines, nacelles, airframe material, and aerodynamics should be undertaken. The culmination of this development program should be the design, fabrication, and flight test of a hypersonic demonstrator (Figure 11). This test vehicle would demonstrate that hypersonic transportation could be routine and would prove the technical viability of the "Orient Express."

Aeronautical System Operational Regions

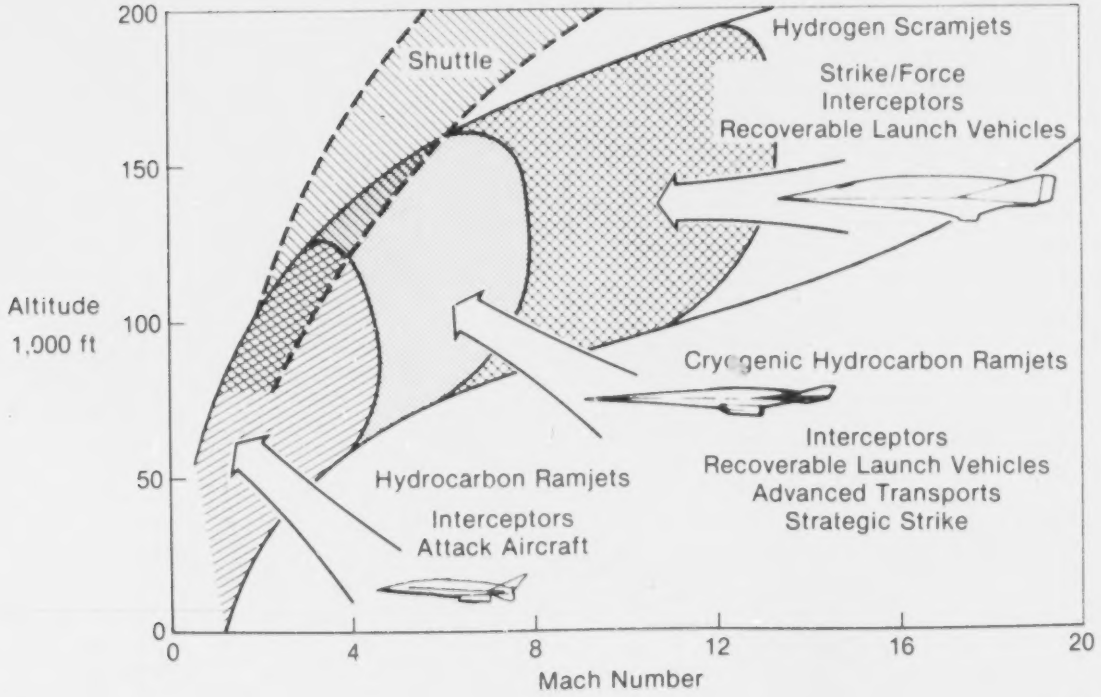

FIGURE 1

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Flight Boundaries

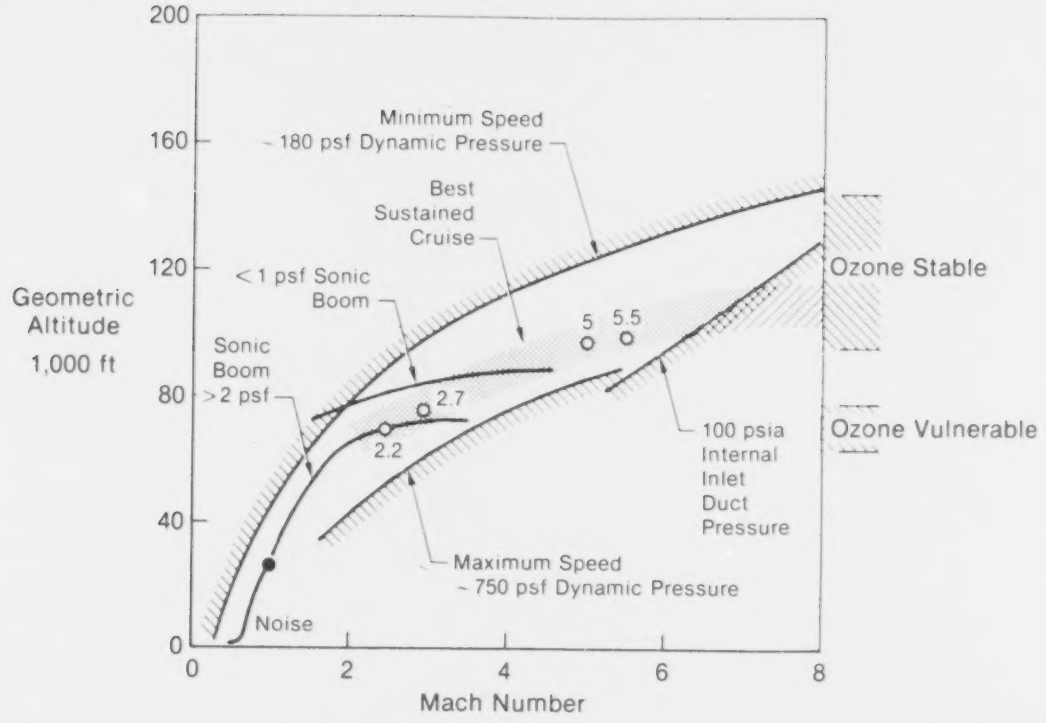

FIGURE 2

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FIGURE 3. MCDONNELL DOUGLAS CORPORATION MACH 2.2 SUPERSONIC TRANSPORT CONCEPT

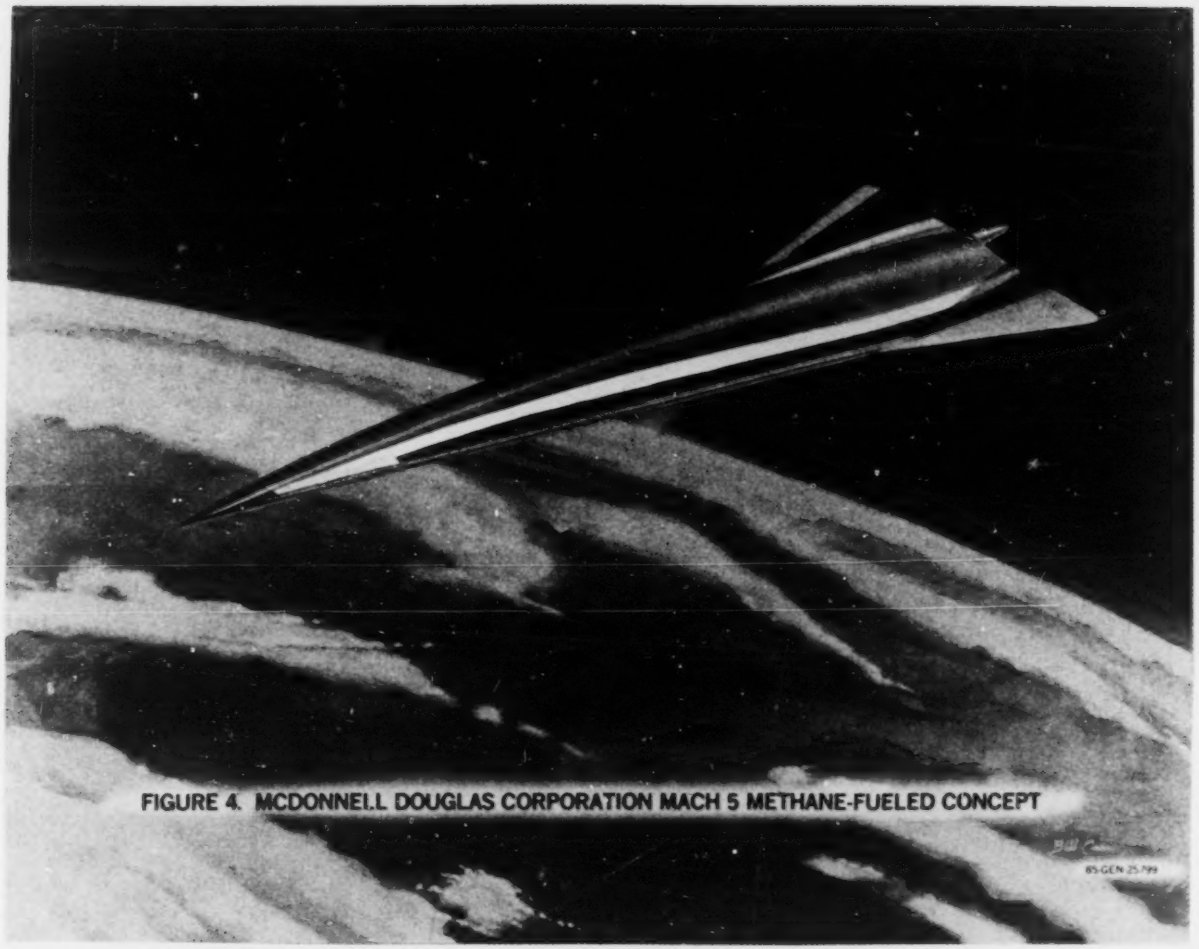


FIGURE 4. MCDONNELL DOUGLAS CORPORATION MACH 5 METHANE-FUELED CONCEPT

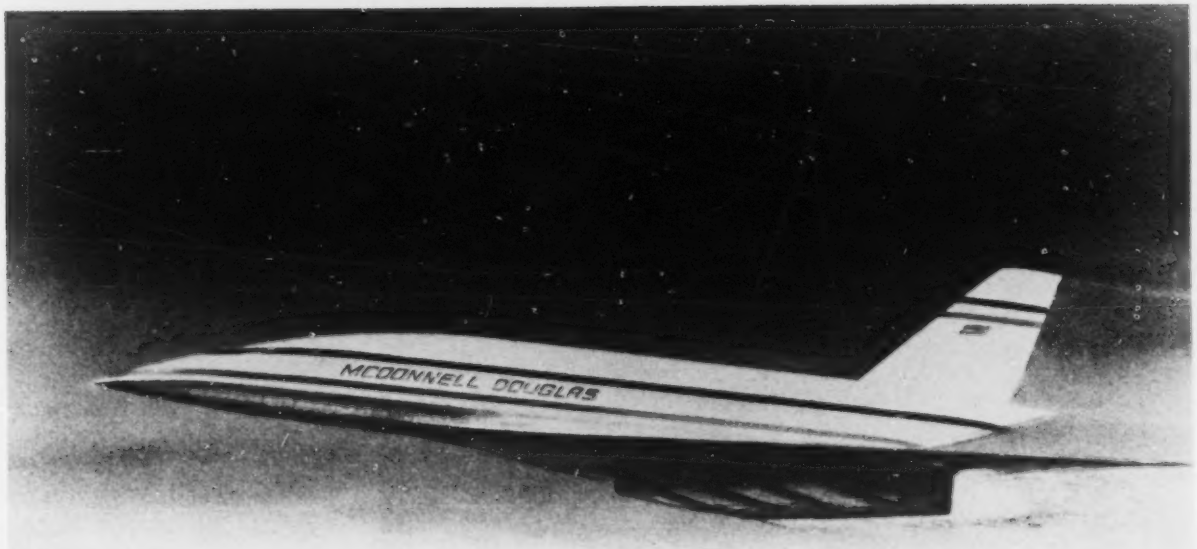


FIGURE 5. MCDONNELL DOUGLAS CORPORATION MACH 5.5 HYDROGEN-FUELED CONCEPT

85-GEN-25736

Aerodynamic Performance Depends on Size and Volume

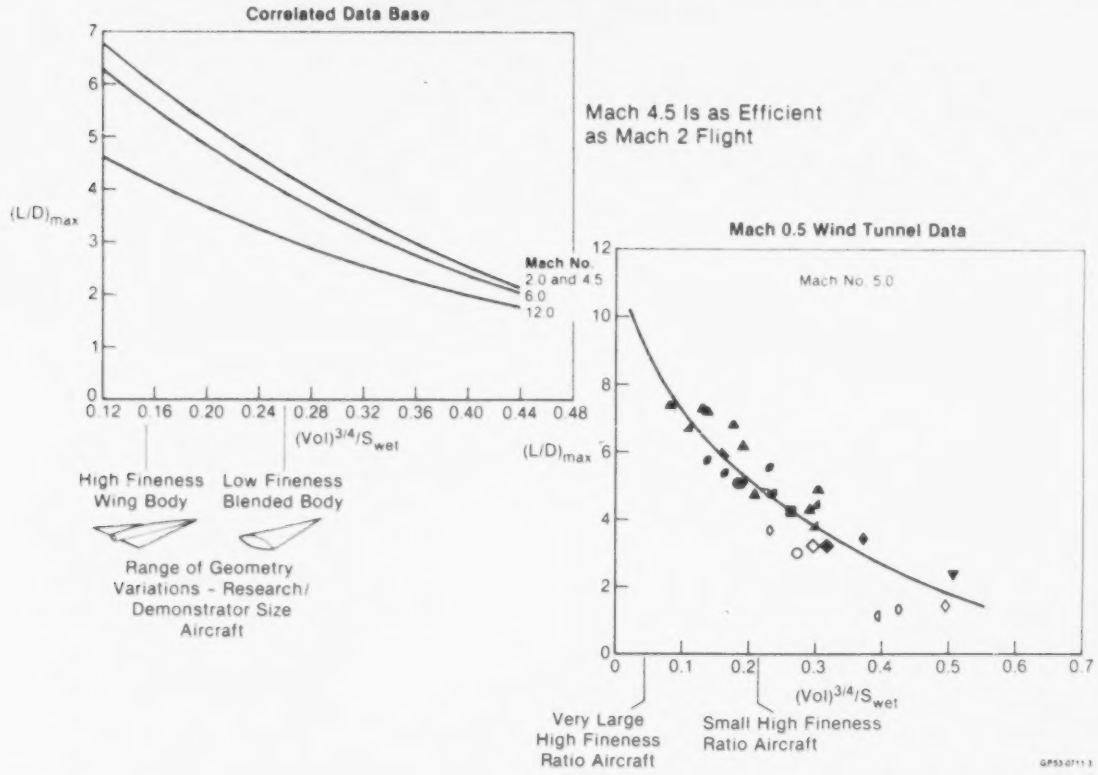
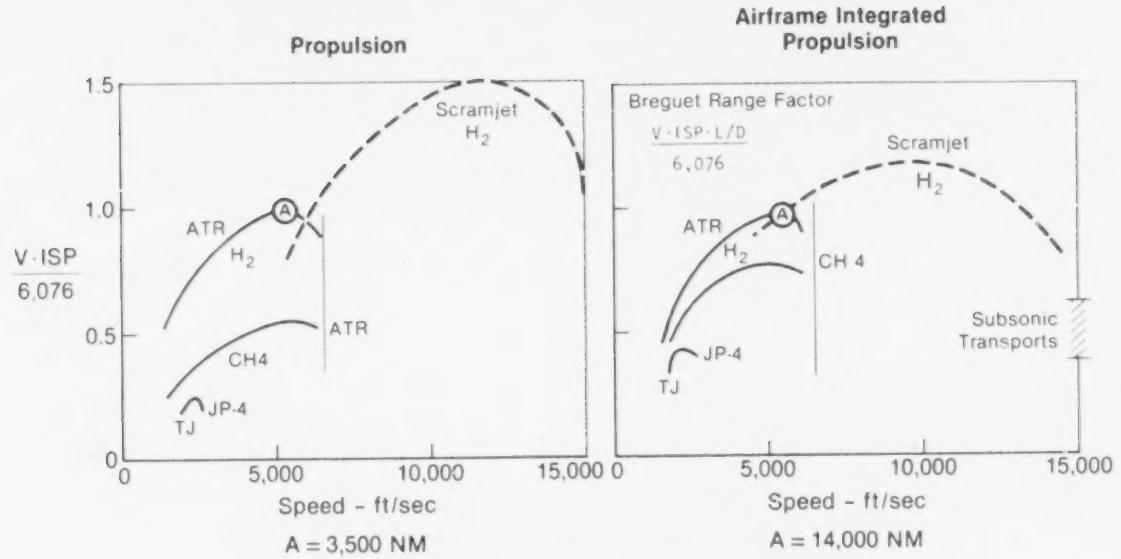


FIGURE 6

Faster Can Mean Less Fuel, Less Cost, Less Time!

Relative Performance
(With Respect to (A))



Mass Flow Specifics Favor Hydrogen
Volumetric Specifics Would Not

FIGURE 7

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Fuel Density Impacts Size, Weight, Thrust

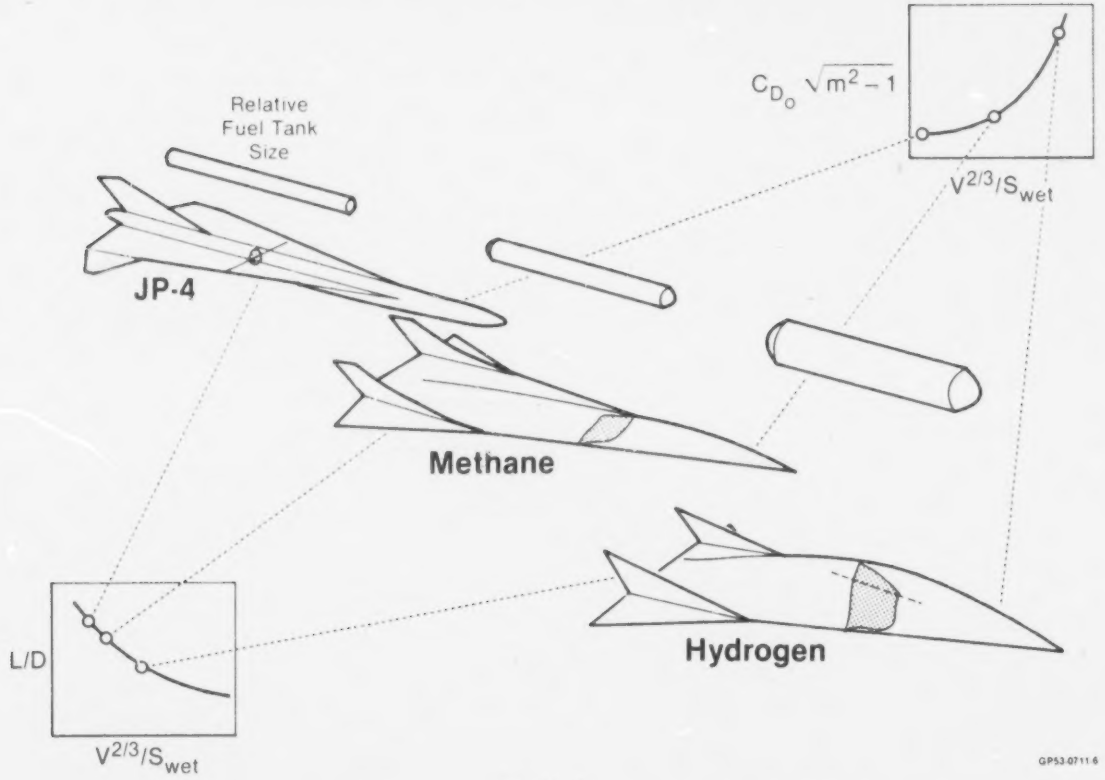

FIGURE 6

RSR Alloys (Alluminum/Titanium), 305 Passenger Transport

Aircraft		DAC Mach 2.2	Mach 5.0	Mach 5.5
Fuel		JP-4	Methane	Hydrogen
Flight Time	hr:min	5:01	2:23	2:16
Flights/8 hr		One	Two	Two
Crew at:		Destination	Home Base	Home Base
Cargo Volume	ft^3	1,850	1,850	1,850
Passenger Vol	ft^3	10,700	10,700	10,700
Fuel Volume	ft^3	7,600	7,800	36,300
Total A/C Vol	ft^3	45,100	29,000	69,600
Planform Area	ft^2	10,000	10,000	10,000
Range Factor	NM	8,590	14,120	20,800
$V^{2/3}/S_{wet}$		0.042	0.036	0.065
L/D		10	9.1	8
Installed ISP	sec	2,340	1,900	2,900
Cruise Speed	kts	1,270	2,940	3,230
Ideal Range	NM	7,799	7,799	7,799
Usable Range	NM	6,500	6,500	6,500
Weight Ratio	TOGW/O.W.E.	2.48	1.74	1.45
Empty Weight	lb	239,300	240,000	305,000
O.W.E.	lb	302,400	305,000	370,000
Fuel Weight	lb	447,600	225,000	167,000
Gross Weight	lb	750,000	530,000	537,000

20,450 wing + tails + engines
24,650 fuselage

Cargo 5,000 lb + 44 lb/passenger @ 10 lb/ft^3
35 ft^3 passenger @ 163 lb = 4.7 lb/ft^3

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FIGURE 9

Hypersonic Transport as Fuel Efficient as Subsonic Wide Body Transport

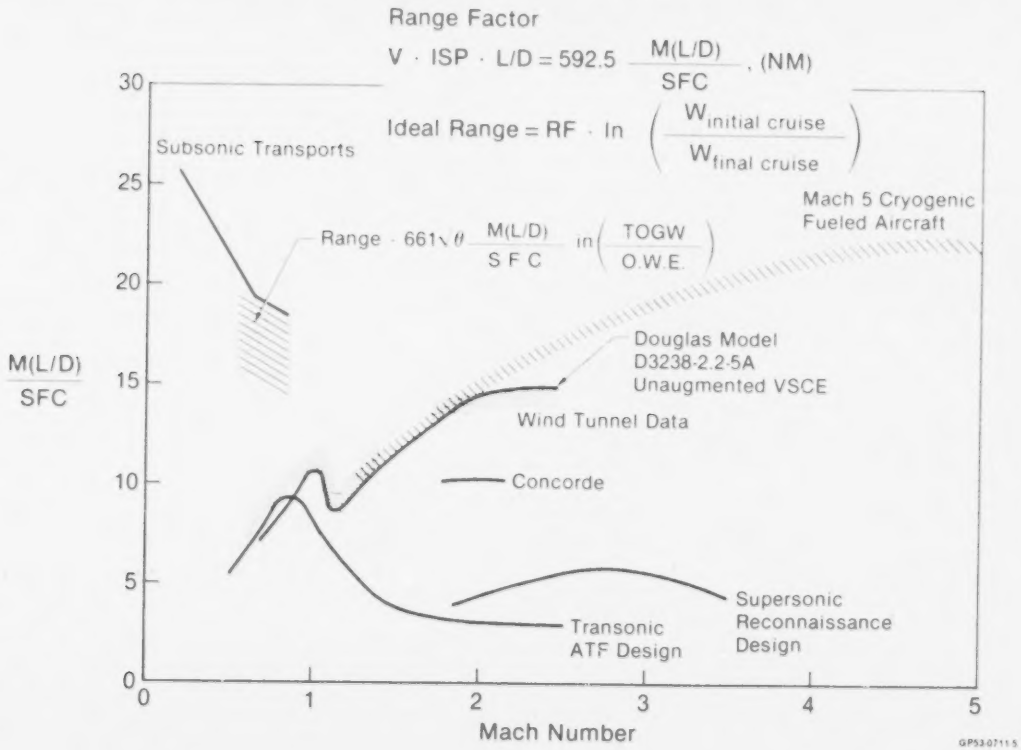
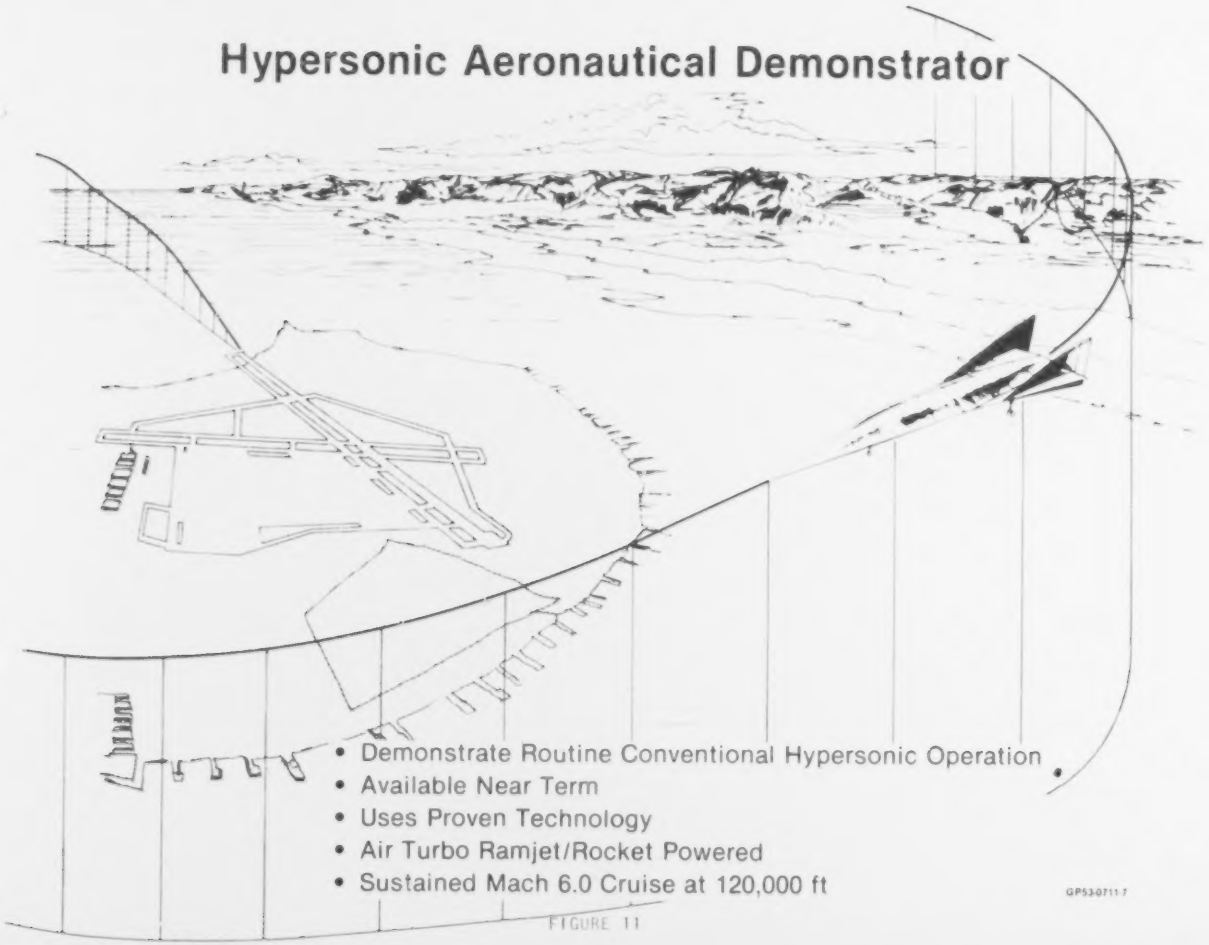


FIGURE 10

Hypersonic Aeronautical Demonstrator



- Demonstrate Routine Conventional Hypersonic Operation
- Available Near Term
- Uses Proven Technology
- Air Turbo Ramjet/Rocket Powered
- Sustained Mach 6.0 Cruise at 120,000 ft

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FIGURE 11